# STOCK ASSESSMENT OF GREENLAND TURBOT

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## Summary

Changes to this year's assessment in the past year include:

1. new summary estimates of retained and discarded Greenland turbot by different target fisheries,
2. update the estimated catch levels by gear type in recent years, and
3. new length frequency and biomass data from the 1998 NMFS eastern Bering Sea shelf survey.

Conditions do not appear to have changed substantively over the past several years. For example, the abundance of Greenland turbot from the eastern Bering Sea (EBS) shelf-trawl survey has found only spotty quantities with very few small fish that were common in the late 1970s and early 1980s. The majority of the catch has shifted to longline gear in recent years. The assessment model analysis was similar to last year but with a slightly higher estimated overall abundance. We attribute this to a slightly improved fit to the longline survey data trend. The target stock size ($B_{40\%}$, female spawning biomass) is estimated at about 139,000 tons while the projected 1999 spawning biomass is about 110,000 tons. The adjusted yield projection from $F_{40\%}$ computations is estimated at 20,000 tons for 1999, and increase of 5,000 from last year's ABC. Given the continued downward abundance trend and no sign of recruitment to the EBS shelf, extra caution is warranted. We therefore recommend that the ABC be set to 15,000 tons (same value as last year). As additional survey information become available and signs of recruitment (perhaps from areas other than the shelf) are apparent, then we believe that the full ABC or increases in harvest may be appropriate for this species.

# 4.1. Introduction

Greenland turbot (*Reinhardtius hippoglossoides*) within the US 200-mile exclusive economic zone are mainly distributed in the eastern Bering Sea (EBS) and Aleutian Islands region. Juveniles are believed to spend the first 3 or 4 years of their lives on the continental shelf and then move to the continental slope (Alton et al. 1988). Juveniles are absent in the Aleutian Islands regions, suggesting that the population in the Aleutians originates from the EBS or elsewhere. In this assessment we assume that the Greenland turbot found in the two regions represent a single management stock.

Prior to 1985 Greenland turbot and arrowtooth flounder were managed together. Since this time the Council has recognized the need for separate management quotas given large differences in the market value between these species. Furthermore, the abundance trends for these two species are clearly distinct (e.g., Wilderbuer and Sample 1992).

The American Fisheries Society uses “Greenland halibut” as the common name for *Reinhardtius hippoglossoides* instead of Greenland turbot. To avoid confusion with the Pacific halibut, *Hippoglossus stenolepis*, we retain the common name of Greenland turbot which is also the “official” market name in the US and Canada (AFS 1991). For further background on this assessment and the methods used refer to Ianelli and Wilderbuer (1995).

# 4.2. Catch history and fishery data

Catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During that period, combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak from 1972 to 1976 of between 63,000 t and 78,000 t annually (Table 4.1; Fig. 4.1). Catches declined after implementation of the MFCMA in 1977, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t. Since 1983, however, trawl harvests declined steadily to a low of 7,100 t in 1988 before increasing slightly to 8,822 t in 1989 and 9,619 t in 1990. This overall decline is due mainly to catch restrictions placed on the fishery because of declining recruitment. For the period 1992–1997, the Council set the TAC’s to 7,000 t as an added conservation measure due to concerns about apparent low levels of recruitment in the past several years. This has resulted in primarily bycatch-only fisheries. The distribution of the longline fishery (in 1997) was mainly concentrated along the slope regions while the trawl fishery catch was more patchy and had highest catch rates in the southeastern area (Fig. 4.2).

Table 4.1. Catches of Greenland turbot by gear type (including discards) since implementation of the MFCMA.

| Year | Trawl | Longline | Total |
|---|---|---|---|
| 1977 | 29,722 | 439 | 30,161 |
| 1978 | 39,560 | 2,629 | 42,189 |
| 1979 | 38,401 | 3,008 | 41,409 |
| 1980 | 48,689 | 3,863 | 52,552 |
| 1981 | 53,298 | 4,023 | 57,321 |
| 1982 | 52,090 | 32 | 52,122 |
| 1983 | 47,529 | 29 | 47,558 |
| 1984 | 23,107 | 13 | 23,120 |
| 1985 | 14,690 | 41 | 14,731 |
| 1986 | 9,864 | 0 | 9,864 |
| 1987 | 9,551 | 34 | 9,585 |
| 1988 | 6,827 | 281 | 7,108 |
| 1989 | 8,293 | 529 | 8,822 |
| 1990 | 10,869 | 577 | 11,446 |
| 1991 | 9,289 | 814 | 10,103 |
| 1992 | 1,559 | 1,130 | 2,689 |
| 1993 | 1,142 | 7,306 | 8,448 |
| 1994 | 6,427 | 3,843 | 10,272 |
| 1995 | 3,978 | 4,214 | 8,193 |
| 1996 | 1,653 | 4,900 | 6,553 |
| 1997 | 1,209 | 6,327 | 7,536 |
| 1998 * | 1,437 | 6,800 | 8,237 |

* Total through 10/01/98, source: NMFS Regional Office, Juneau, AK

The early catch information includes only the tonnage of Greenland turbot retained onboard Bering Sea fishing vessels or processed onshore (as reported by PacFIN). However, Greenland turbot are also discarded overboard in other trawl target fisheries. The following estimates of discards from 1990-97 were estimated from a combination of discard rates observed from vessels with 100% observer sampling and NMFS regional office weekly processor reports. These values were used in the assessment model.

| Year | Trawl | Longline | Total |
|---|---|---|---|
| 1990 | na | Na | 1,250 t |
| 1991 | na | Na | 3,427 t |
| 1992 | na | Na | 1,013 t |
| 1993 | na | Na | 1,333 t |
| 1994 | 854 t | 1,858 t | 2,711 t |
| 1995 | 535 t | 2,087 t | 2,622 t |
| 1996 | 354 t | 1,042 t | 1,396 t |
| 1997 | 289 t | 1,533 t | 1,822 t |
| 1998* | 140 t | 661 t | 801 t |

* Total through 10/01/98, source: NMFS Regional Office, Juneau, AK

Additional information on 1996 and 1997 retained and discarded catch of Greenland turbot indicates that a large fraction of discards occurred due to the sablefish fishery (Fig. 4.3). The proportion of discards attributed to the sablefish fishery decreased slightly in 1997, though the total discard levels were similar.

### *Catch and catch per unit effort (CPUE)*

The catch data were used as presented above for both the longline and trawl fisheries. The early catches included Greenland turbot and arrowtooth flounder together. To separate them, we assumed that the ratio of the two species for the years 1960-64 was the same as the mean ratio caught by USSR vessels from 1965-69.

A CPUE index derived in Alton et al. (1988) for the years 1978-84 for the trawl fishery was used as an index of abundance in the stock synthesis model:

| Year | 78 | 79 | 80 | 81 | 82 | 83 | 84 |
|---|---|---|---|---|---|---|---|
| CPUE Index | 291 | 316 | 449 | 409 | 235 | 195 | 335 |

In last year's SAFE report, we presented a preliminary examination of recent catch rate data based on the NMFS NORPAC observer database. Due to the short seasons for the directed fishery in recent years we concluded that these data are not reliable as an index of abundance.

### *Size and age composition*

No age composition information is available from the fisheries or surveys. However, extensive length frequency compositions have been collected by the NMFS observer program from the period 1980 to 1991. The length composition data from the trawl and longline fishery and the expected values from the assessment model are presented in the section below titled "Model results and evaluation" (Fig. 4.8). This information is used in the assessment model and adds to our ability to estimate size-specific selectivity patterns in addition to year-class variability.

## 4.3. Resource Surveys

Abundance estimates for juvenile Greenland turbot on the EBS shelf are provided annually by AFSC trawl surveys. The older juveniles and adults on the slope have been assessed every third year since 1979 (also in 1981) during U.S.-Japan cooperative surveys. The slope surveys were conducted by Japanese shore-based (Hokuten) trawlers chartered by the Japan Fisheries Agency until 1985. In 1988, the NOAA R/V Miller Freeman surveyed the resources on the EBS slope region. In this same year, chartered Japanese vessels performed side-by-side trawl experiments with the Miller Freeman for calibration purposes. Due to limited vessel time, the area and number of stations sampled by the Miller Freeman was less than sampled by the Japanese trawlers in most previous years. The Miller Freeman sampled 133 stations over a depth interval of 200-800 m while during earlier slope surveys the Japanese vessels usually sampled 200-300 stations over a depth interval of 200-1,000 m (Table 4.2).

Table 4.2. Historical fishing mortality rates (Model 3, combined gear types), female spawner biomass, and beginning of year age 1+ biomass values by year and model configuration.

| | Eastern | | Bering Sea | Aleutians |
|---|---|---|---|---|
| **Year** | **Shelf** | **Slope** | **Shelf and Slope Combined** | |
| 1975 | 126,700 | --- | --- | --- |
| 1979 | 225,600 | 123,000 | 348,600 | --- |
| 1980 | 172,200 | --- | --- | 48,700 |
| 1981 | 86,800 | 99,600 | 186,400 | --- |
| 1982 | 48,600 | 90,600 | 139,200 | --- |
| 1983 | 35,100 | --- | --- | 63,800 |
| 1984 | 17,900 | --- | --- | --- |
| 1985 | 7,700 | 79,200 | 86,900 | --- |
| 1986 | 5,600 | --- | --- | 76,500 |
| 1987 | 10,600 | --- | --- | --- |
| 1988 | 14,800 | 42,700* | 57,500* | --- |
| 1989 | 8,900 | --- | --- | --- |
| 1990 | 14,300 | --- | --- | --- |
| 1991 | 13,000 | 40,500 | 53,900* | 12,100** |
| 1992 | 24,000 | --- | --- | --- |
| 1993 | 30,400 | --- | --- | --- |
| 1994 | 48,800 | --- | --- | 29,106 ** |
| 1995 | 34,800 | --- | --- | --- |
| 1996 | 30,300 | --- | --- | --- |
| 1997 | 29,218 | --- | --- | 32,027** |
| 1998 | 28,126 | --- | --- | --- |

* The 1988 and 1991 estimate are from 200-800 m whereas the earlier slope estimates are from 200-1,000 m.

** The 1980, 1983, and 1986 surveys sampled 1-900 m whereas the 1991, 1994 and 1997 survey sampled only 1-500 m.

We believe that the U.S. and Japanese trawl slope-surveys under-estimate the actual biomass of Greenland turbot when swept-area expansions are made. Thus, we treat these as indices of relative abundance. That is, the species appears to extend beyond the area of the survey and that the ability to tend bottom in the deeper waters may be compromised.

The combined estimates from the shelf and slope indicate a decline in EBS abundance for the 4 years of observations that were available during 1979-1985. After 1985, the slope biomass estimates (and the 1991 Aleutian Islands estimate) are not comparable to previous years due to differences in depths sampled. The interpretation of the CPUE data from these surveys, however, suggests a moderate decline in abundance between 1985 and 1991. The average shelf-survey biomass estimate during the last 6 years (1993-1998) is 33,604 tons with a slightly declining trend during this period.

The following table summarizes the sampling that has occurred for the EBS bottom trawl survey data since 1982:

| Year | No. hauls | No. Lengths |
|---|---|---|
| 1982 | 329 | 969 |
| 1983 | 354 | 951 |
| 1984 | 355 | 536 |
| 1985 | 353 | 196 |
| 1986 | 354 | 195 |
| 1987 | 342 | 82 |
| 1988 | 353 | 200 |
| 1989 | 353 | 183 |
| 1990 | 352 | 232 |
| 1991 | 351 | 360 |
| 1992 | 336 | 440 |
| 1993 | 355 | 400 |
| 1994 | 355 | 398 |
| 1995 | 356 | 313 |
| 1996 | 355 | 297 |
| 1997 | 356 | 197 |
| 1998 | 355 | 93 |

Biomass estimates from U.S.-Japan cooperative surveys in the Aleutian Islands region suggest an increasing trend from 48,700 t in 1980 to 76,560 t in 1986 (the 1991 estimate is not directly comparable). Relative to the trend in the EBS, the apparent increased abundance in the Aleutian Island Region may be due to migration of older fish from the EBS. In 1997 NMFS AFSC conducted a triennial bottom-trawl survey of the Aleutian Islands region using methods described in Harrison (1993). The preliminary area-swept estimate of biomass from this survey is 32,027 tons. This compares with a value of 29,106 tons estimated from the 1994 survey. Examining the distribution of where the survey found Greenland turbot in the Aleutian Islands reveals similar patterns between the 1994 and 1997 surveys.

Previously, the eastern Bering Sea Cooperative longline survey was incorporated for use as a relative abundance index. A bootstrap resampling scheme was used to provide confidence bounds on the annual relative abundance estimates. We used the median values of the bootstrap estimates as our relative population index. This index represents numerical abundance whereas the shelf and slope surveys represent biomass indices. We continue to work on methods of incorporating recent domestic longline surveys which have this year been extended into the Bering Sea and part of the Aleutian Islands. This new area covered represents a smaller region than in past but shows that about 27% of the population along the slope regions is found within the northeast (NE) and southeast (SE) portions of the Aleutian Islands compared to the abundances along the slope of the EBS:

| **Relative Popln. Number** | | **Year** | |
|---|---|---|---|
| **Area** | **1996** | **1997** | **1998** |
| Bering 4 | | 11,729 | |
| Bering 3 | | 6,172 | |
| Bering 2 | | 27,936 | |
| Bering 1 | | 13,491 | |
| NE Aleutians | 23,133 | | 17,120 |
| SE Aleutians | 2,142 | | 1,806 |

A time series of estimated size composition of the population was available for the shelf and slope trawl surveys and for the longline survey. These are presented in the form of estimated length frequencies of the population vulnerable to the survey sampling gear. The slope surveys typically sample more turbot than the shelf trawl surveys, consequently, the number of fish measured in the slope surveys is greater. The time series of length frequencies from the longline survey was presented in Ianelli et al. (1994). The Greenland turbot size composition from the 1996 shelf trawl survey is given in Fig. 4.4. For data from other years refer to Fig. 4.8 (showing data and model fits).

# 4.4. Analytic approach

The use of the stock synthesis program (Methot 1989, 1990) to model the Greenland turbot stock was presented in previous assessments (Ianelli et al. 1994, 1995). Prior to this time, stock assessments of Greenland turbot in the eastern Bering Sea and Aleutian Islands have relied in part on stock reduction analysis (SRA) to provide historical trends in the fishery (Wilderbuer and Sample 1992).

## 4.4.1. Model Details

Stock synthesis (Methot 1989) functions by simulating both the dynamics of the population and the processes by which the population is observed. This simulation, which incorporates both imprecision and bias in the observations, is used to predict expected values for the observations. These expected values are then compared to the actual observations (data) from surveys and the fishery.

Catch data used in the stock synthesis model were from 1960 to 1998. The last seven years were adjusted to include discards. It was assumed that the stock was at or close to its virgin biomass level at the beginning of the catch data time series.

Model parameters are estimated by maximizing the log likelihood (L) of the predicted observations given the data. Data are classified into different components. For example, age composition from a survey and catch per unit effort (CPUE) from a fishery are different components. The total L is a sum of the likelihoods for each component. The total L may also include a component for a stock-recruitment relationship and penalty functions to help stabilize parameter estimates. The likelihood components may be weighted by an emphasis factor. For Greenland Turbot in the EBS the model included two fisheries, those using longline and trawl gear, and three surveys. Table 4.3 summarizes the extent of the data used in the different likelihood components.

Table 4.2. Data sets used in the stock synthesis model for Greenland Turbot in the EBS. All size and age data are specified by sex.

| Data Component | Years of data |
|---|---|
| Survey Size at age data | 1975, 1979-82 |
| Shelf Survey: size composition and biomass estimates | 1979-1998 |
| Slope Survey: size composition and biomass estimates | 1979, 81, 82, 85, 88, 91 |
| Longline Survey: size composition and abundance index | 1984-1993 |
| Total Fishery Catch Data | 1960-1998 |
| Trawl CPUE Index | 1978-1984 |
| Trawl Catch Size Composition | 1977-87, 1989-91, 1993-96 |
| Longline Catch Size Composition | 1977, 1979-85, 1992-98 |

The stock synthesis model allows for several forms of underlying stock-recruitment relationships. We chose the Beverton-Holt (1957) form as parameterized by Kimura (1988). Because annual recruitments are estimated as parameters in the model, they can be thought of as “anomalies” from the underlying stock-recruitment curve. These recruitment anomalies can be due to process and observation errors. Process errors refer to the real differences from the mean stock-recruitment curve caused by natural variation in recruitment success. Observation errors refer to our ability to estimate the true recruitment levels due to sampling problems. In this application, observation error is considered negligible compared to the magnitude of recruitment variability (process error). Consequently, the underlying parameters of the stock-recruit curve play an insignificant role in fitting the model to the data. A resampling scheme of estimated recruitment levels was used for the projections. For further details on the model specifications of the length-version of the stock synthesis program, see Thompson *et al.* (Pacific cod chapter, this volume).

### *Selectivity Patterns*

A dome-shaped size-based selectivity function (Methot 1990) was estimated for each survey and fishery described below. For the trawl fishery, the time periods of length frequency data collections from the domestic and foreign fleet did not overlap. Consequently, we treated the foreign and domestic trawl data as from a single fishery and simply let the selectivity pattern be different between the respective periods. Because larger fish have been observed in the EBS shelf region trawl surveys, selectivity for the two most recent years was estimated separately from the earlier data.

## 4.4.2. Parameters estimated independently

### *Natural mortality, length at age, length-weight relationship*

The natural mortality of Greenland turbot was assumed to be 0.18. This estimate was used because it is slightly less than that of other flatfish species with a slightly lower maximum age. Greenland turbot taken by the commercial fishery have been aged as old as 21 years.

Parameters describing length-at-age are estimated within the model. We do assume that the length at age 1 is the same for both sexes and that the variability in length at age 1 has a 8% CV and that the variability in length at age 21 has a CV of 7%. This appears to encompass the observed variability in length-at-age.

As in the previous assessments, size-at-age information from surveys conducted between 1976-82 were used in the model to help estimate the relationship between age and length. The length-weight relationship for Greenland turbot estimated by Ianelli et al. (1993) was:

$$w = 2.69 \times 10^{-6} L^{3.3092} \quad \text{for females}$$

and

$$w = 6.52 \times 10^{-6} L^{3.068} \quad \text{for males}$$

where $L$ = length in mm, and $w$ = weight in grams. Last year we re-evaluating our treatment of the length-weight relationships within the stock-synthesis program, we found that re-calibration was required. This involved ensuring the proper conversion of units (e.g., cm to kg, versus mm to grams).

### *Maturation and fecundity*

Maturation and fecundity by size or age is poorly understood for Greenland turbot. Alton *et al.* (1988) present the results from studies of Greenland turbot in different areas in addition to the EBS region. For this analysis, we have chose a logistic size-maturity relationship which has 50% of the female population mature at 60 cm; 2% and 98% of the females are assumed to be mature at about 50 and 70 cm respectively. This is based on an approximation from D'yakov's (1982) study.

## 4.4.3. Parameters estimated within the model

The key parameters estimated within the model include:

- annual recruitment estimates from 1960-1995 (1965-1969 aggregated to have a single mean value),
- selectivity parameters for the 2 fisheries, and 3 surveys,
- growth parameters: 5 parameters (2 for each sex, one in common),
- parameter that scales the expected value of recruitment, and
- effective effort-fishing mortality rates (solved by matching predicted catch biomass to the observed catch biomass exactly), 1960-1998.

# 4.5. Results/Model evaluation

Size composition data are not available until 1977 hence we are unable to resolve recruitment strength information during the early period (1960s) with the model. Initially, we set the individual recruitment estimates from 1960-69 equal to that predicted by an equilibrium stock-recruitment relationship. This yielded a poor fit to the size composition data and estimated a virgin recruitment level that gave the mean unfished biomass more than 1.8 million metric tons. When all recruitment deviations were estimated (the full model), a single large deviation resulted in the early part of the time series. This indicated a year class more than an order of magnitude greater than the mean estimated recruitment since 1970. Both the full model and the equilibrium recruitment models were therefore unsatisfactory. To compensate, we pooled recruitment deviation estimates from 1965-68 as in Ianelli et al. (1993).

Initial model configurations with the shelf survey biomass estimates treated as an absolute abundance index and the slope surveys as a relative index gave unreasonable biomass levels. The best fit occurred when the slope abundance index represented only about 5% of the biomass available to the slope survey. That means that a slope survey biomass estimate of 50,000 tons would expand to 1,000,000 tons of actual biomass available. This value of "Q" or catchability for the slope survey is unreasonably low compared to values of Q common for other flatfish species. Consequently, we investigated the effect of different fixed values of slope survey Q on the fit to individual data components. Results from this exercise indicate that the majority of the likelihood components were consistent with a low Q value for the slope survey, but that the likelihood surface was relatively flat with respect to Q (Ianelli et al. 1993). As in previous years, we found a pattern of poorer fits as the slope-survey value of Q was increased:

| | Description | | Total Likelihood |
|---|---|---|---|
| Model 1 | Slope Q fixed at 0.25 | (high biomass) | -3463.05 |
| Model 2 | Slope Q fixed at 0.50 | (mod. Biomass) | -3496.53 |
| Model 3 | Slope Q fixed at 0.75 | (low biomass) | -3521.53 |

### *Trends in Abundance*

The fits to the abundance indices are given in Fig. 4.5. The assessment model predictions for shelf survey biomass are far below the observed estimates during the early years and subsequently track the survey estimates well. These data are consistent with the conclusion of Alton et al. (1988) that recruitment of juveniles in the EBS has been low since the early 1980s. The reason that the model fits the early period of the shelf trawl survey index poorly is because such high levels of recruitment are inconsistent with observations of numbers of older fish later in the time series. The overall trend for the slope survey estimates is mimicked by the assessment model, but indicates biases based on the fixed Q values used in each model for the slope survey. The general trend of the longline survey index shows increasing numbers while the model predicts declines. The model's reluctance to fit the apparent increasing trend from the longline survey data reflects the relatively large standard errors associated with this index. If we increase the model emphasis on the survey longline trend, the fits to the other surveys degrades considerably (Ianelli et al. 1995). The effect of high emphasis on the longline survey (increasing biomass trend) would indicate a much higher level of current spawner biomass.

The biomass of Greenland turbot has roughly doubled during the 1970s from the early 1960s level and is currently about half of the unfished level. The 1998 total beginning of the year biomass (age 1 and older) ranges from about 170,000 to 335,000 tons with slope survey Q set to 0.75 and 0.25, respectively (Fig 4.6). In past years, extra caution has been exercised in setting harvest levels of Greenland turbot because of the lack of recruitment success in recent years. For this reason, we selected the conservative assumption of Model 3, with Q for the slope survey set equal to 0.75 for our ABC recommendations. It should be noted that the slope survey biomass estimates do not include the biomass estimates from the

Aleutian Islands, which averages about one third of the total population biomass. It is therefore very likely that the biomass estimates from this model configuration are biased towards low values. The historical fishing mortality rates (combined gears) increased over time and was highest in 1982 and 1983 (Table 4.4). The effect of different models on historical biomass levels is also presented in Table 4.4. The estimated historical numbers at age based on Model 3 show the change in the age structure over time (Table 4.5).

Table 4.4. Historical fishing mortality rates (Model 3, combined gear types), female spawner biomass, and beginning of year age 1+ biomass values by year and model configuration.

| | | Female Spawner Biomass | | | Total Age 1+ Biomass | | |
|---|---|---|---|---|---|---|---|
| Year | F | Model 1 | Model 2 | Model 3 | Model 1 | Model 2 | Model 3 |
| 1960 | 0.05 | 452,441 | 369,681 | 337,841 | 773,350 | 631,375 | 576,118 |
| 1961 | 0.09 | 436,078 | 353,207 | 321,261 | 746,962 | 604,955 | 549,695 |
| 1962 | 0.10 | 410,219 | 327,211 | 295,136 | 705,851 | 563,734 | 508,496 |
| 1963 | 0.06 | 384,306 | 301,214 | 269,071 | 665,545 | 523,167 | 467,867 |
| 1964 | 0.06 | 371,441 | 288,344 | 256,245 | 647,358 | 504,272 | 448,759 |
| 1965 | 0.02 | 358,120 | 275,005 | 242,956 | 635,508 | 490,555 | 434,179 |
| 1966 | 0.03 | 356,490 | 273,307 | 241,312 | 650,718 | 502,394 | 444,477 |
| 1967 | 0.05 | 354,127 | 270,650 | 238,568 | 685,882 | 530,757 | 469,477 |
| 1968 | 0.06 | 348,197 | 263,966 | 231,571 | 738,528 | 572,814 | 506,091 |
| 1969 | 0.06 | 341,575 | 255,714 | 222,600 | 806,753 | 627,211 | 553,209 |
| 1970 | 0.04 | 346,825 | 256,955 | 222,132 | 886,307 | 691,463 | 609,508 |
| 1971 | 0.07 | 379,224 | 281,316 | 242,860 | 978,422 | 767,932 | 677,754 |
| 1972 | 0.12 | 424,939 | 316,317 | 272,469 | 1,032,484 | 809,491 | 712,981 |
| 1973 | 0.10 | 465,305 | 345,091 | 294,947 | 1,025,310 | 794,337 | 694,000 |
| 1974 | 0.13 | 510,300 | 378,328 | 321,849 | 1,007,335 | 772,589 | 670,644 |
| 1975 | 0.12 | 532,461 | 391,343 | 329,965 | 955,996 | 720,718 | 618,728 |
| 1976 | 0.13 | 531,643 | 386,262 | 322,671 | 910,924 | 676,082 | 574,413 |
| 1977 | 0.07 | 506,758 | 361,927 | 298,694 | 867,388 | 633,534 | 532,594 |
| 1978 | 0.10 | 488,774 | 347,020 | 285,365 | 860,305 | 626,141 | 525,559 |
| 1979 | 0.11 | 463,044 | 324,640 | 264,715 | 845,965 | 609,693 | 508,910 |
| 1980 | 0.14 | 444,102 | 307,932 | 249,232 | 838,724 | 597,915 | 496,161 |
| 1981 | 0.16 | 423,100 | 287,963 | 230,104 | 823,408 | 576,412 | 473,242 |
| 1982 | 0.13 | 405,267 | 269,068 | 211,301 | 798,684 | 546,140 | 441,935 |
| 1983 | 0.13 | 398,563 | 258,674 | 200,000 | 768,084 | 512,723 | 408,533 |
| 1984 | 0.07 | 399,313 | 253,374 | 192,972 | 728,241 | 474,175 | 371,445 |
| 1985 | 0.05 | 412,561 | 260,207 | 197,885 | 699,836 | 451,612 | 351,804 |
| 1986 | 0.03 | 421,643 | 265,712 | 202,575 | 670,121 | 431,503 | 335,824 |
| 1987 | 0.03 | 420,284 | 265,301 | 203,046 | 638,635 | 412,594 | 321,863 |
| 1988 | 0.03 | 405,855 | 256,332 | 196,595 | 606,041 | 393,628 | 307,969 |
| 1989 | 0.04 | 383,541 | 242,834 | 186,749 | 575,861 | 377,211 | 296,530 |
| 1990 | 0.06 | 355,453 | 225,277 | 173,308 | 544,345 | 359,286 | 283,448 |
| 1991 | 0.07 | 326,560 | 206,970 | 158,895 | 510,559 | 338,422 | 267,166 |
| 1992 | 0.03 | 303,661 | 193,325 | 148,462 | 478,653 | 318,724 | 251,806 |
| 1993 | 0.08 | 290,762 | 188,459 | 146,280 | 458,818 | 309,548 | 246,449 |
| 1994 | 0.08 | 273,681 | 178,951 | 139,348 | 435,373 | 295,941 | 236,459 |
| 1995 | 0.08 | 255,589 | 167,960 | 130,862 | 409,575 | 279,602 | 223,692 |
| 1996 | 0.07 | 241,443 | 159,767 | 124,823 | 384,797 | 264,229 | 211,961 |
| 1997 | 0.09 | 231,619 | 154,689 | 121,511 | 360,451 | 249,323 | 200,790 |
| 1998 | 0.11 | 220,718 | 148,419 | 117,015 | 334,653 | 233,064 | 188,391 |

Table 4.5. Estimated beginning of year numbers of Greenland turbot by age and sex (millions) estimated for Model 3.

**Females**

| Yr | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 19.10 | 57.68 | 48.06 | 39.75 | 32.09 | 25.46 | 6.07 | 4.53 | 3.48 | 2.72 | 2.16 | 1.95 | 1.50 | 1.18 | 0.96 | 0.80 | 0.66 | 0.55 | 0.46 | 0.38 | 1.91 |
| 71 | 12.04 | 15.94 | 48.10 | 39.88 | 32.47 | 25.92 | 20.50 | 4.88 | 3.64 | 2.80 | 2.19 | 1.74 | 1.57 | 1.21 | 0.95 | 0.77 | 0.64 | 0.53 | 0.44 | 0.37 | 1.84 |
| 72 | 15.40 | 10.03 | 13.27 | 39.70 | 31.95 | 25.47 | 20.20 | 15.96 | 3.80 | 2.83 | 2.18 | 1.70 | 1.35 | 1.22 | 0.94 | 0.74 | 0.60 | 0.50 | 0.41 | 0.35 | 1.72 |
| 73 | 25.53 | 12.81 | 8.34 | 10.86 | 30.87 | 23.96 | 18.90 | 14.95 | 11.80 | 2.81 | 2.10 | 1.61 | 1.26 | 1.00 | 0.90 | 0.70 | 0.55 | 0.45 | 0.37 | 0.31 | 1.53 |
| 74 | 39.57 | 21.26 | 10.66 | 6.85 | 8.55 | 23.59 | 18.15 | 14.29 | 11.30 | 8.91 | 2.12 | 1.58 | 1.22 | 0.95 | 0.75 | 0.68 | 0.53 | 0.41 | 0.34 | 0.28 | 1.38 |
| 75 | 17.34 | 32.93 | 17.67 | 8.71 | 5.30 | 6.37 | 17.36 | 13.32 | 10.48 | 8.28 | 6.54 | 1.56 | 1.16 | 0.89 | 0.70 | 0.55 | 0.50 | 0.39 | 0.30 | 0.25 | 1.22 |
| 76 | 33.67 | 14.43 | 27.37 | 14.45 | 6.77 | 3.97 | 4.71 | 12.82 | 9.83 | 7.74 | 6.12 | 4.83 | 1.15 | 0.86 | 0.66 | 0.52 | 0.41 | 0.37 | 0.28 | 0.22 | 1.08 |
| 77 | 32.22 | 28.02 | 11.99 | 22.38 | 11.22 | 5.06 | 2.93 | 3.48 | 9.45 | 7.25 | 5.70 | 4.51 | 3.56 | 0.85 | 0.63 | 0.49 | 0.38 | 0.30 | 0.27 | 0.21 | 0.96 |
| 78 | 39.05 | 26.86 | 23.35 | 9.91 | 18.02 | 8.86 | 3.98 | 2.30 | 2.73 | 7.41 | 5.68 | 4.47 | 3.53 | 2.79 | 0.66 | 0.49 | 0.38 | 0.30 | 0.24 | 0.21 | 0.92 |
| 79 | 30.09 | 32.53 | 22.36 | 19.22 | 7.87 | 13.95 | 6.81 | 3.05 | 1.76 | 2.09 | 5.66 | 4.33 | 3.40 | 2.68 | 2.11 | 0.50 | 0.37 | 0.29 | 0.22 | 0.18 | 0.85 |
| 80 | 16.29 | 25.07 | 27.08 | 18.41 | 15.25 | 6.09 | 10.70 | 5.21 | 2.33 | 1.35 | 1.59 | 4.30 | 3.28 | 2.57 | 2.03 | 1.59 | 0.38 | 0.28 | 0.22 | 0.17 | 0.78 |
| 81 | 10.06 | 13.56 | 20.85 | 22.19 | 14.37 | 11.51 | 4.55 | 7.97 | 3.88 | 1.73 | 1.00 | 1.17 | 3.16 | 2.41 | 1.88 | 1.48 | 1.16 | 0.28 | 0.21 | 0.16 | 0.69 |
| 82 | 5.18 | 8.37 | 11.27 | 17.03 | 17.16 | 10.69 | 8.46 | 3.33 | 5.83 | 2.82 | 1.26 | 0.72 | 0.84 | 2.27 | 1.73 | 1.35 | 1.06 | 0.83 | 0.20 | 0.15 | 0.60 |
| 83 | 3.66 | 4.31 | 6.96 | 9.20 | 13.15 | 12.72 | 7.83 | 6.18 | 2.43 | 4.26 | 2.06 | 0.92 | 0.53 | 0.62 | 1.66 | 1.26 | 0.98 | 0.77 | 0.61 | 0.14 | 0.55 |
| 84 | 5.61 | 3.04 | 3.58 | 5.68 | 7.12 | 9.78 | 9.36 | 5.75 | 4.54 | 1.78 | 3.12 | 1.51 | 0.67 | 0.39 | 0.45 | 1.22 | 0.92 | 0.72 | 0.57 | 0.44 | 0.51 |
| 85 | 9.89 | 4.68 | 2.54 | 2.96 | 4.56 | 5.60 | 7.66 | 7.32 | 4.49 | 3.54 | 1.39 | 2.44 | 1.18 | 0.53 | 0.30 | 0.35 | 0.95 | 0.72 | 0.56 | 0.44 | 0.74 |
| 86 | 15.25 | 8.25 | 3.90 | 2.10 | 2.41 | 3.66 | 4.48 | 6.12 | 5.84 | 3.59 | 2.83 | 1.11 | 1.95 | 0.94 | 0.42 | 0.24 | 0.28 | 0.76 | 0.58 | 0.45 | 0.95 |
| 87 | 8.88 | 12.73 | 6.88 | 3.24 | 1.72 | 1.96 | 2.97 | 3.63 | 4.95 | 4.73 | 2.90 | 2.29 | 0.90 | 1.58 | 0.76 | 0.34 | 0.20 | 0.23 | 0.61 | 0.47 | 1.13 |
| 88 | 6.00 | 7.41 | 10.62 | 5.72 | 2.66 | 1.40 | 1.58 | 2.40 | 2.93 | 4.00 | 3.83 | 2.35 | 1.85 | 0.73 | 1.27 | 0.62 | 0.27 | 0.16 | 0.18 | 0.50 | 1.29 |
| 89 | 6.24 | 5.01 | 6.18 | 8.83 | 4.71 | 2.17 | 1.14 | 1.29 | 1.96 | 2.39 | 3.26 | 3.12 | 1.91 | 1.51 | 0.59 | 1.04 | 0.50 | 0.22 | 0.13 | 0.15 | 1.45 |
| 90 | 9.21 | 5.22 | 4.18 | 5.16 | 7.38 | 3.93 | 1.80 | 0.94 | 1.05 | 1.58 | 1.93 | 2.62 | 2.50 | 1.54 | 1.21 | 0.48 | 0.83 | 0.40 | 0.18 | 0.10 | 1.29 |
| 91 | 12.84 | 7.69 | 4.36 | 3.49 | 4.31 | 6.16 | 3.25 | 1.46 | 0.75 | 0.83 | 1.25 | 1.52 | 2.06 | 1.97 | 1.21 | 0.95 | 0.37 | 0.65 | 0.32 | 0.14 | 1.09 |
| 92 | 4.50 | 10.72 | 6.42 | 3.64 | 2.92 | 3.60 | 5.09 | 2.63 | 1.16 | 0.59 | 0.65 | 0.98 | 1.19 | 1.62 | 1.54 | 0.94 | 0.74 | 0.29 | 0.51 | 0.25 | 0.96 |
| 93 | 3.39 | 3.76 | 8.96 | 5.37 | 3.04 | 2.44 | 3.00 | 4.22 | 2.17 | 0.96 | 0.48 | 0.53 | 0.80 | 0.97 | 1.32 | 1.26 | 0.77 | 0.61 | 0.24 | 0.42 | 0.99 |
| 94 | 3.01 | 2.83 | 3.14 | 7.48 | 4.48 | 2.54 | 2.03 | 2.49 | 3.48 | 1.78 | 0.78 | 0.39 | 0.43 | 0.64 | 0.77 | 1.04 | 0.99 | 0.60 | 0.47 | 0.19 | 1.09 |
| 95 | 3.02 | 2.51 | 2.36 | 2.62 | 6.25 | 3.74 | 2.10 | 1.66 | 2.01 | 2.79 | 1.42 | 0.62 | 0.31 | 0.34 | 0.50 | 0.60 | 0.81 | 0.77 | 0.47 | 0.37 | 0.98 |
| 96 | 4.81 | 2.53 | 2.10 | 1.97 | 2.19 | 5.22 | 3.11 | 1.73 | 1.36 | 1.63 | 2.25 | 1.14 | 0.49 | 0.24 | 0.26 | 0.39 | 0.47 | 0.63 | 0.60 | 0.36 | 1.05 |
| 97 | 4.81 | 4.02 | 2.11 | 1.75 | 1.65 | 1.83 | 4.35 | 2.58 | 1.43 | 1.11 | 1.33 | 1.81 | 0.91 | 0.39 | 0.19 | 0.21 | 0.31 | 0.37 | 0.50 | 0.47 | 1.10 |
| 98 | 4.81 | 4.02 | 3.36 | 1.76 | 1.46 | 1.38 | 1.52 | 3.61 | 2.13 | 1.17 | 0.90 | 1.06 | 1.44 | 0.72 | 0.31 | 0.15 | 0.16 | 0.24 | 0.28 | 0.38 | 1.21 |

**Males**

| Yr | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21+ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 19.10 | 57.68 | 48.06 | 39.78 | 32.22 | 25.66 | 6.12 | 4.56 | 3.50 | 2.74 | 2.18 | 1.97 | 1.53 | 1.20 | 0.97 | 0.80 | 0.67 | 0.56 | 0.46 | 0.39 | 1.95 |
| 71 | 12.04 | 15.94 | 48.10 | 39.90 | 32.57 | 26.08 | 20.68 | 4.93 | 3.67 | 2.81 | 2.21 | 1.75 | 1.59 | 1.23 | 0.97 | 0.78 | 0.65 | 0.54 | 0.45 | 0.37 | 1.88 |
| 72 | 15.40 | 10.03 | 13.27 | 39.73 | 32.10 | 25.66 | 20.38 | 16.12 | 3.84 | 2.86 | 2.19 | 1.72 | 1.37 | 1.24 | 0.96 | 0.75 | 0.61 | 0.50 | 0.42 | 0.35 | 1.76 |
| 73 | 25.53 | 12.81 | 8.34 | 10.87 | 31.12 | 24.25 | 19.11 | 15.11 | 11.93 | 2.84 | 2.11 | 1.62 | 1.27 | 1.01 | 0.92 | 0.71 | 0.56 | 0.45 | 0.37 | 0.31 | 1.57 |
| 74 | 39.57 | 21.26 | 10.66 | 6.86 | 8.61 | 23.93 | 18.43 | 14.46 | 11.42 | 9.02 | 2.15 | 1.60 | 1.22 | 0.96 | 0.76 | 0.69 | 0.54 | 0.42 | 0.34 | 0.28 | 1.42 |
| 75 | 17.34 | 32.93 | 17.67 | 8.72 | 5.35 | 6.46 | 17.68 | 13.55 | 10.62 | 8.38 | 6.61 | 1.57 | 1.17 | 0.90 | 0.71 | 0.56 | 0.51 | 0.40 | 0.31 | 0.25 | 1.26 |
| 76 | 33.67 | 14.43 | 27.37 | 14.47 | 6.83 | 4.03 | 4.80 | 13.08 | 10.01 | 7.84 | 6.19 | 4.88 | 1.16 | 0.87 | 0.67 | 0.52 | 0.42 | 0.38 | 0.29 | 0.23 | 1.12 |
| 77 | 32.22 | 28.02 | 11.99 | 22.41 | 11.32 | 5.14 | 2.99 | 3.55 | 9.65 | 7.38 | 5.78 | 4.56 | 3.60 | 0.86 | 0.64 | 0.49 | 0.39 | 0.31 | 0.28 | 0.22 | 1.00 |
| 78 | 39.05 | 26.86 | 23.35 | 9.92 | 18.11 | 8.98 | 4.05 | 2.35 | 2.79 | 7.57 | 5.79 | 4.54 | 3.58 | 2.83 | 0.67 | 0.50 | 0.39 | 0.30 | 0.24 | 0.22 | 0.96 |
| 79 | 30.09 | 32.53 | 22.36 | 19.24 | 7.92 | 14.09 | 6.91 | 3.11 | 1.80 | 2.14 | 5.80 | 4.43 | 3.47 | 2.74 | 2.16 | 0.52 | 0.38 | 0.30 | 0.23 | 0.19 | 0.90 |
| 80 | 16.29 | 25.07 | 27.08 | 18.42 | 15.35 | 6.16 | 10.84 | 5.30 | 2.38 | 1.38 | 1.63 | 4.43 | 3.39 | 2.65 | 2.09 | 1.65 | 0.39 | 0.29 | 0.23 | 0.18 | 0.83 |
| 81 | 10.06 | 13.56 | 20.85 | 22.21 | 14.49 | 11.66 | 4.62 | 8.09 | 3.95 | 1.77 | 1.03 | 1.21 | 3.29 | 2.51 | 1.97 | 1.55 | 1.23 | 0.29 | 0.22 | 0.17 | 0.75 |
| 82 | 5.18 | 8.37 | 11.27 | 17.05 | 17.31 | 10.86 | 8.61 | 3.39 | 5.93 | 2.89 | 1.30 | 0.75 | 0.89 | 2.40 | 1.83 | 1.43 | 1.13 | 0.89 | 0.21 | 0.16 | 0.67 |
| 83 | 3.66 | 4.31 | 6.96 | 9.21 | 13.27 | 12.95 | 7.99 | 6.30 | 2.48 | 4.33 | 2.11 | 0.95 | 0.55 | 0.65 | 1.76 | 1.34 | 1.05 | 0.83 | 0.66 | 0.16 | 0.61 |
| 84 | 5.61 | 3.04 | 3.58 | 5.69 | 7.18 | 9.96 | 9.56 | 5.88 | 4.63 | 1.82 | 3.18 | 1.55 | 0.69 | 0.40 | 0.48 | 1.29 | 0.99 | 0.77 | 0.61 | 0.48 | 0.56 |
| 85 | 9.89 | 4.68 | 2.54 | 2.96 | 4.59 | 5.68 | 7.81 | 7.48 | 4.59 | 3.62 | 1.42 | 2.48 | 1.21 | 0.54 | 0.31 | 0.37 | 1.01 | 0.77 | 0.61 | 0.48 | 0.82 |
| 86 | 15.25 | 8.25 | 3.90 | 2.10 | 2.42 | 3.69 | 4.55 | 6.24 | 5.98 | 3.67 | 2.89 | 1.13 | 1.98 | 0.97 | 0.43 | 0.25 | 0.30 | 0.81 | 0.62 | 0.48 | 1.04 |
| 87 | 8.88 | 12.73 | 6.88 | 3.24 | 1.73 | 1.97 | 3.00 | 3.68 | 5.05 | 4.84 | 2.97 | 2.34 | 0.92 | 1.61 | 0.78 | 0.35 | 0.20 | 0.24 | 0.66 | 0.50 | 1.23 |
| 88 | 6.00 | 7.41 | 10.62 | 5.72 | 2.66 | 1.41 | 1.59 | 2.42 | 2.98 | 4.09 | 3.91 | 2.40 | 1.89 | 0.74 | 1.30 | 0.63 | 0.28 | 0.17 | 0.20 | 0.53 | 1.41 |
| 89 | 6.24 | 5.01 | 6.18 | 8.84 | 4.72 | 2.18 | 1.15 | 1.30 | 1.98 | 2.43 | 3.33 | 3.19 | 1.96 | 1.54 | 0.61 | 1.06 | 0.52 | 0.23 | 0.13 | 0.16 | 1.58 |
| 90 | 9.21 | 5.22 | 4.18 | 5.16 | 7.38 | 3.94 | 1.82 | 0.95 | 1.07 | 1.61 | 1.97 | 2.70 | 2.58 | 1.58 | 1.24 | 0.49 | 0.85 | 0.42 | 0.19 | 0.11 | 1.40 |
| 91 | 12.84 | 7.69 | 4.36 | 3.49 | 4.31 | 6.16 | 3.28 | 1.50 | 0.77 | 0.86 | 1.29 | 1.57 | 2.14 | 2.04 | 1.25 | 0.98 | 0.39 | 0.68 | 0.33 | 0.15 | 1.19 |
| 92 | 4.50 | 10.72 | 6.42 | 3.64 | 2.92 | 3.60 | 5.13 | 2.70 | 1.22 | 0.62 | 0.69 | 1.02 | 1.24 | 1.69 | 1.61 | 0.98 | 0.77 | 0.30 | 0.53 | 0.26 | 1.05 |
| 93 | 3.39 | 3.76 | 8.96 | 5.37 | 3.04 | 2.44 | 3.01 | 4.27 | 2.24 | 1.01 | 0.51 | 0.57 | 0.84 | 1.02 | 1.39 | 1.32 | 0.81 | 0.64 | 0.25 | 0.44 | 1.08 |
| 94 | 3.01 | 2.83 | 3.14 | 7.48 | 4.48 | 2.54 | 2.03 | 2.50 | 3.55 | 1.86 | 0.83 | 0.42 | 0.47 | 0.69 | 0.84 | 1.13 | 1.08 | 0.66 | 0.52 | 0.20 | 1.23 |
| 95 | 3.02 | 2.51 | 2.36 | 2.62 | 6.25 | 3.74 | 2.11 | 1.68 | 2.06 | 2.89 | 1.51 | 0.67 | 0.34 | 0.37 | 0.55 | 0.67 | 0.90 | 0.86 | 0.52 | 0.41 | 1.14 |
| 96 | 4.81 | 2.53 | 2.10 | 1.97 | 2.19 | 5.22 | 3.12 | 1.76 | 1.39 | 1.69 | 2.36 | 1.23 | 0.55 | 0.28 | 0.30 | 0.45 | 0.54 | 0.73 | 0.69 | 0.42 | 1.24 |
| 97 | 4.81 | 4.02 | 2.11 | 1.75 | 1.65 | 1.83 | 4.35 | 2.60 | 1.46 | 1.15 | 1.39 | 1.94 | 1.01 | 0.45 | 0.23 | 0.25 | 0.36 | 0.44 | 0.59 | 0.56 | 1.35 |
| 98 | 4.81 | 4.02 | 3.36 | 1.76 | 1.46 | 1.38 | 1.53 | 3.63 | 2.16 | 1.21 | 0.95 | 1.15 | 1.59 | 0.82 | 0.36 | 0.18 | 0.20 | 0.29 | 0.35 | 0.48 | 1.54 |

### *Selectivity*

Selectivity of Greenland turbot varied considerably between all of the surveys and fisheries. The shelf survey selected only small fish whereas the slope survey caught much larger fish. A similar pattern was observed between the trawl and longline fisheries with the longline fishery consistently catching larger Greenland turbot (Fig. 4.7). Note that the average selectivity estimates for the slope and shelf surveys indicate that our surveys do not sample intermediate size fish (35-50cm) very well. The reason for this is not clear; however, we feel that it is related to the apparent bi-modality in the size distribution observed in the trawl fishery (see Fig. 4.8).

### *Fit to Size Composition Data*

Size composition observations from the fisheries and surveys are generally poorly matched by the model predictions (Fig. 4.8). These figures display an "effective *N*" value for each year and gear type. This is a rough measure of how well the model fits the data. Higher values for effective *N* imply better fits to the data. This lack of fit can be attributed to several reasons. First, the influence of size composition data on the total likelihood for a given gear type and year depends on the number of Greenland turbot measured. In some years, relatively few fish were measured so adjustments of the model to those data would depend on the trade-off in fitting other data, which may have had more extensive sampling. Second, unaccounted for fish movement and hence changing availability affects fits to size composition data when an "average" gear selectivity is used. Finally, natural mortality rate is undoubtedly variable among cohorts and years, the extent of which would affect our ability to model the age structure of the population accurately. The nature of the inconsistencies among data types is presented below, particularly as they pertain to assessing the current stock status.

### *Recruitment*

Recruitment of young juvenile Greenland turbot has been poor since the early 1980s as indicated by trawl surveys on the EBS shelf. There is evidence from slope surveys that this poor recruitment has reduced abundance of the exploitable stock. Consequently, we expect continued reduction of the exploitable stock into the late 1990s. As presented in previous assessments, there were several strong year-classes through the 1970s, which were followed by a series of poor recruitment of Greenland turbot since the early 1980s (Fig. 4.9). Preliminary analyses on fitting the stock-recruitment relationship indicated that the residuals were highly auto-correlated. At this time, the authors feel that the environmental conditions are likely to dominate any relationship between spawner biomass and recruitment in explaining recruitment variability. Therefore, analyses of stock-recruitment relationship to calculate an MSY value were not pursued.

## 4.6. Projections and harvest alternatives

### *Maximum Sustainable Yield*

Maximum sustainable yield (MSY) calculations require assumptions about the stock recruitment relationship, which for Greenland turbot may be impractical as many functional forms can fit the data equally well. As presented above, the harvest strategy relative to reductions in spawner biomass per recruit (e.g., $F_{40\%}$) was selected in the absence of information on the stock-recruitment productivity relationship required for calculating MSY levels.

### *ABC and Overfishing levels*

The recommended harvest levels vary considerably among models depending on the assumptions made about the catchability coefficients from the slope-trawl survey (Table 4.6). Since there are several areas of uncertainty surrounding this assessment, we select Model 3 for the basis for recommendations.

We computed $B_{40\%}$ value by using the mean recruitment estimated for the period 1960-1996. The results indicate that the long-term average female spawner biomass is around 139,000 tons. The current estimate of 1999 female spawner biomass is about 110,000 tons indicating that the adjustment is about 79% to the fishing mortality. We approximate this application by simply applying it to the ABC value under the unadjusted $F_{40\%}$. This results in recommendation of 20,000 t. Given the magnitude of uncertainty surrounding future selectivities among the fisheries and the general uncertainty about the current model specification, we feel that fine-tuning the adjustment would be misleading relative to the overall uncertainty.

To enhance the rebuilding potential of Greenland turbot in the EBS and Aleutian Islands region and given the continued downward abundance trend and no sign of recruitment to the EBS shelf, extra caution is warranted further developing this fishery. **We therefore recommend an ABC of 15,000 tons** (same value as last year). As additional survey information become available and signs of recruitment (perhaps from areas other than the shelf) are apparent, then we believe that the full ABC may be appropriate for this species. Also, the last area-swept quantitative survey in the adult habitat was conducted in 1991. NMFS plans to survey the slope region of the EBS again in the near future.

Our recommendation for overfishing, based on the adjusted $F_{30\%}$ rate under Model 3, is 22,271 t corresponding to an (adjusted) full-selection $F$ of 0.28. The value of the Council's overfishing definition depends on the age-specific selectivity of the fishing gear, the somatic growth rate, natural mortality, and the age specific fecundity. As this rate depends on assumed selectivity, future yields are sensitive to relative gear-specific harvest levels. Because harvests of this resource is not allocated by gear type, the unpredictable nature of future harvests between gears is an added source of uncertainty. However, this uncertainty is considerably less than uncertainty related to treatment of survey biomass levels, i.e., factors which contribute to estimating absolute biomass (Table 4.6).

Table 4.6. Yield estimates for 1997 based on different fishing mortality rates and model assumptions. The values in bold face were selected for ABC recommendations.

| **F** | **Model 1 Q=.25** | **Model 2 Q=.50** | **Model 3 Q=.75** |
|---|---|---|---|
| $F_{40\%}$ | 0.255 | 0.260 | 0.262 |
| $F_{30\%}$ | 0.394 | 0.404 | 0.408 |
| 1999 Yield $F_{40\%}$ | 47,018 | 31,958 | 25,295 |
| 1999 Yield $F_{30\%}$ | 69,382 | 47,280 | 37,511 |
| 1999 Spawn. Bio. | 206,510 | 139,350 | 109,976 |
| $B_{40\%}$ | 184,661 | 151,577 | 138,822 |
| $B_{1999}/B_{40\%}$ | 112% | 92% | 79% |
| Adj. $F_{40\%}$ Yield | 47,018 | 29,380 | 20,039 |
| Adj. $F_{30\%}$ Yield | 69,382 | 43,466 | 29,716 |

### *Projected Catch and Abundance*

Projections of fishable biomass five years into the future under alternative fishing mortality rates were examined. The same natural mortality and growth parameters that were used in the previous stock synthesis runs were employed for the projections. The results suggest a continued decline until about 2004 (Fig. 4.10. To examine the long-term aspects of the fishery we perform a simulation where recruitment was re-sampled from the estimates of recruitment available from the model for the years 1960-1996. The yield (fishing at the unadjusted $F_{40\%}$ harvest rate, with equal trawl and longline $F$ levels) gives a broad range values and of future spawning stock sizes (Fig. 4.11). Yield drops as low as 10,000 t per year at less than half the current stock size and averages about 28,000 tons at the $B_{40\%}$ level.

# 4.7. Other Considerations

## 4.7.1. Subarea Allocation

In this assessment we have adopted the hypothesis proposed by Alton et al. (1989) regarding the stock structure of Greenland turbot in the eastern Bering Sea and Aleutian Islands regions. Briefly, spawning is thought to occur throughout the adult range with post-larval settlement occurring on the shelf in shallow areas. The young fish on the shelf begin to migrate to the slope region at about age 4 or 5. In our treatment, the spawning stock includes adults in the Aleutian Islands and the eastern Bering Sea. In support of this hypothesis, we examined the length compositions from the Aleutian Islands surveys and found a lack of small Greenland turbot, which suggests that these fish migrate from other areas (Ianelli et al. 1993). Historically, the catches between the Aleutian Islands and eastern Bering Sea has varied (Table 4.7).

Table 4.7. Estimated total Greenland turbot harvest by area.

| Year | EBS | Aleutians |
|---|---|---|
| 1977 | 27,708 | 2,453 |
| 1978 | 37,423 | 4,766 |
| 1979 | 34,998 | 6,411 |
| 1980 | 48,856 | 3,697 |
| 1981 | 52,921 | 4,400 |
| 1982 | 45,805 | 6,317 |
| 1983 | 43,443 | 4,115 |
| 1984 | 21,317 | 1,803 |
| 1985 | 14,698 | 33 |
| 1986 | 7,710 | 2,154 |
| 1987 | 6,519 | 3,066 |
| 1988 | 6,064 | 1,044 |
| 1989 | 4,061 | 4,761 |
| 1990 | 7,702 | 2,494 |
| 1991 | 4,075 | 3,636 |
| 1992 | 951 | 725 |
| 1993 | 5,125 | 3,323 |
| 1994 | 6,902 | 3,032 |
| 1995 | 5,713 | 2,086 |
| 1996 | 4,386 | 1,578 |
| 1997 | 6,594 | 943 |

Since we acknowledge having limited information on the movement and recruitment processes for this species and in the interest of harvesting the "stock" evenly, we recommend that the ABC be split between regions. Based on eastern Bering Sea slope survey estimates and Aleutian Islands surveys, the proportion of the adult biomass in the Aleutian Islands region has ranged from 24% to 49%. We therefore recommend the ABC for the Aleutian Islands be set 33% of the total ABC, with 67% allocated to the eastern Bering Sea. These rates represent the mid-point of the values observed from biomass estimates. For Model 3 (slope survey Q=.75), the allocation would thus be:

| | |
|---|---|
| Aleutian Islands | 5,000 t |
| Eastern Bering Sea | 10,000 t |
| Total | 15,000 t |

### 4.7.2. Ecosystem considerations

Greenland turbot have undergone dramatic declines in the abundance of immature fish on the EBS shelf region compared to observations during the late 1970's. It may be that the high level of abundance during this period was unusual and the current level is typical for Greenland turbot life history pattern. Without further information on where different life-stages are currently residing, we can only speculate on the plausibility of this scenario. Several major predators on the shelf were at relatively low stock sizes during the late 1970's (e.g., Pacific cod, Pacific halibut) and these increased to peak levels during the mid 1980's. Perhaps this shift in abundance has reduced the survival of juvenile Greenland turbot in the EBS shelf. Alternatively, the shift in recruitment patterns for Greenland turbot may be due to the documented environmental regime that occurred during the late 1970's. That is, perhaps the critical life history stages are subject to different oceanographic conditions that affect the abundance of juvenile Greenland turbot on the EBS shelf.

Currently, the ecosystem group within the REFM Division is actively evaluating the pattern of mortality between different species in the EBS. One aspect of this work involves developing a multi-species model. Preliminary results from this effort indicate that Greenland turbot is an important predator.

To our knowledge, only five recaptured tagged Greenland turbot have been reported. The total number of releases by year were: 1985—262 fish; 1986—320 fish, 1987—241 fish. This low number of recaptures may be due to under-reporting and/or poor tag-retention properties.

Since the slope region of the Bering Sea has not been surveyed by trawl gear since 1991 and the cooperative longline survey in the Bering Sea region has been terminated, the sources of information needed for stock assessment continue to decline. The Eastern Bering Sea shelf survey gives some indication of recruitment, however, the extent to which Greenland turbot depend on this region as a "nursery" area is unclear. In 1997 the NMFS longline survey was extended to the Eastern Bering Sea slope region. While this survey is designed for assessment of sablefish, the depth ranges covered also can provide a reasonable index for Greenland turbot (Ianelli and Wilderbuer 1995).

The NMFS Auke Bay Lab staff continued to conduct a feasibility study on tagging Greenland turbot from the longline survey in 1997 and have continued to tag Greenland turbot on an opportunistic basis in 1998. The methods seem to be working well with minimal interference with normal survey operations. This year 66 Greenland turbot were tagged and released bringing the total releases of this species in the last two years up to 361.

## 4.8. Summary

The management parameters of interest derived from this assessment are presented in Table 4.8. Please note, however, that management actions should be based on a more complete evaluation of the alternatives presented above rather than the single values given here.

Table 4.8. Summary management values based on this assessment. Note that the fishing mortality rates assume 50% contribution from longline gear and 50% from trawl.

| Management Parameter | Value |
|---|---|
| M | 0.18 yr-1 |
| Approximate age at full recruitment | 10 years |
| $F_{30\%}$ | 0.41 |
| $F_{40\%}$ | 0.26 |
| $B_{40\%}$ | 139,000 t |
| 1999 female spawning biomass | 110,000 t |
| $F_{ABC} = F_{40\%} \times \frac{15{,}000}{25{,}295}$ | **0.195*** |
| **Recommended ABC** | **15,000 t** |
| $F_{overfishing} = F_{30\%}$ | 0.41 |
| **Overfishing level** | **29,700 t** |

*adjusted to be less than the $F_{40\%}$ under tier 3b.

## 4.9. Acknowledgments

Mike Sigler compiled the summaries for the 1996-1998 longline survey data.

## 4.10. References

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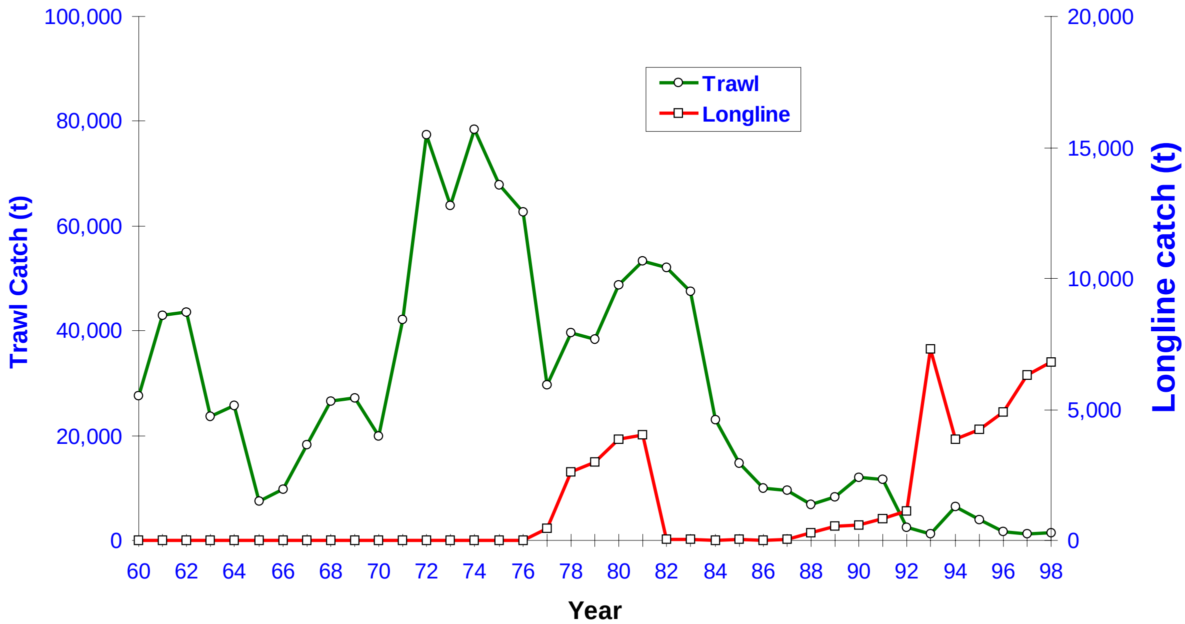
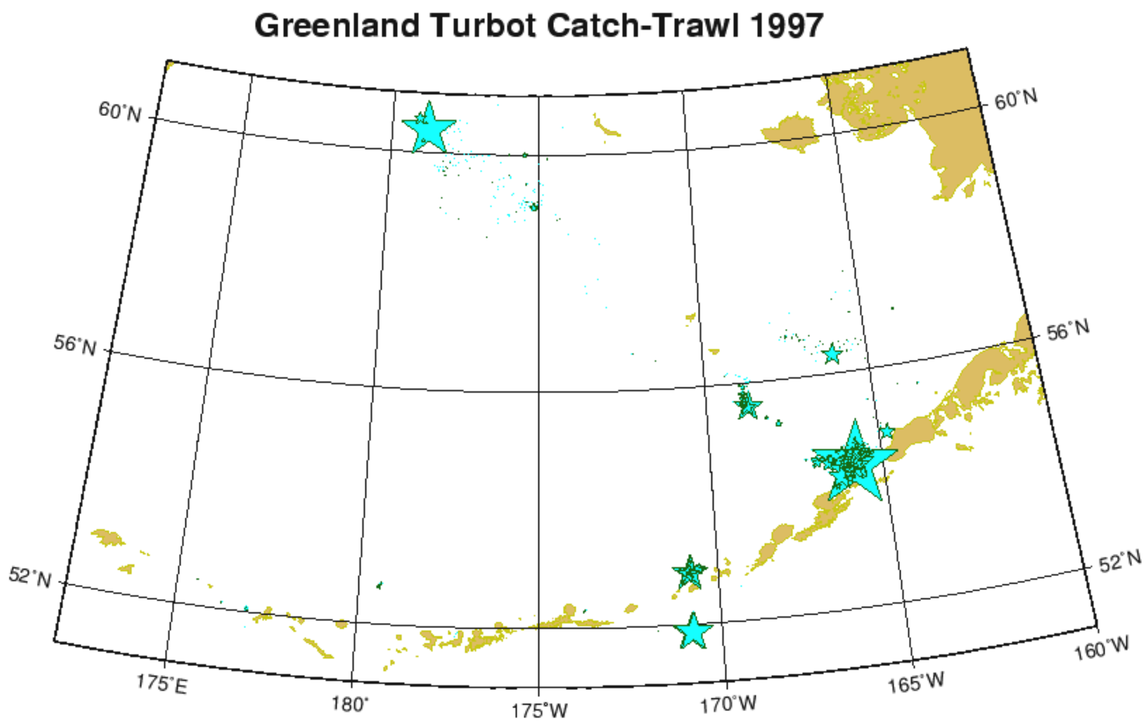



Figure 4.1. Comparison of trawl (1960-98) and longline (1977-98) catches of Greenland turbot in the combined EBS/AI area.



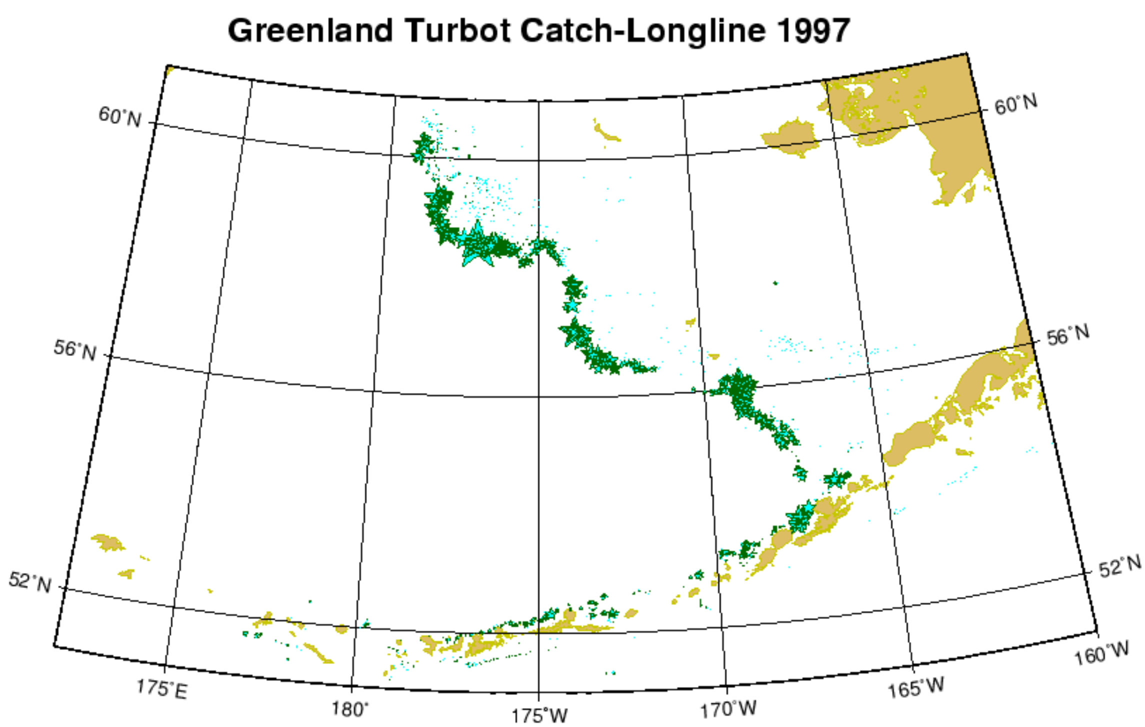




Figure 4.2. 1995 longline and trawl locations of successful Greenland turbot fishing operations based on NMFS observer data.

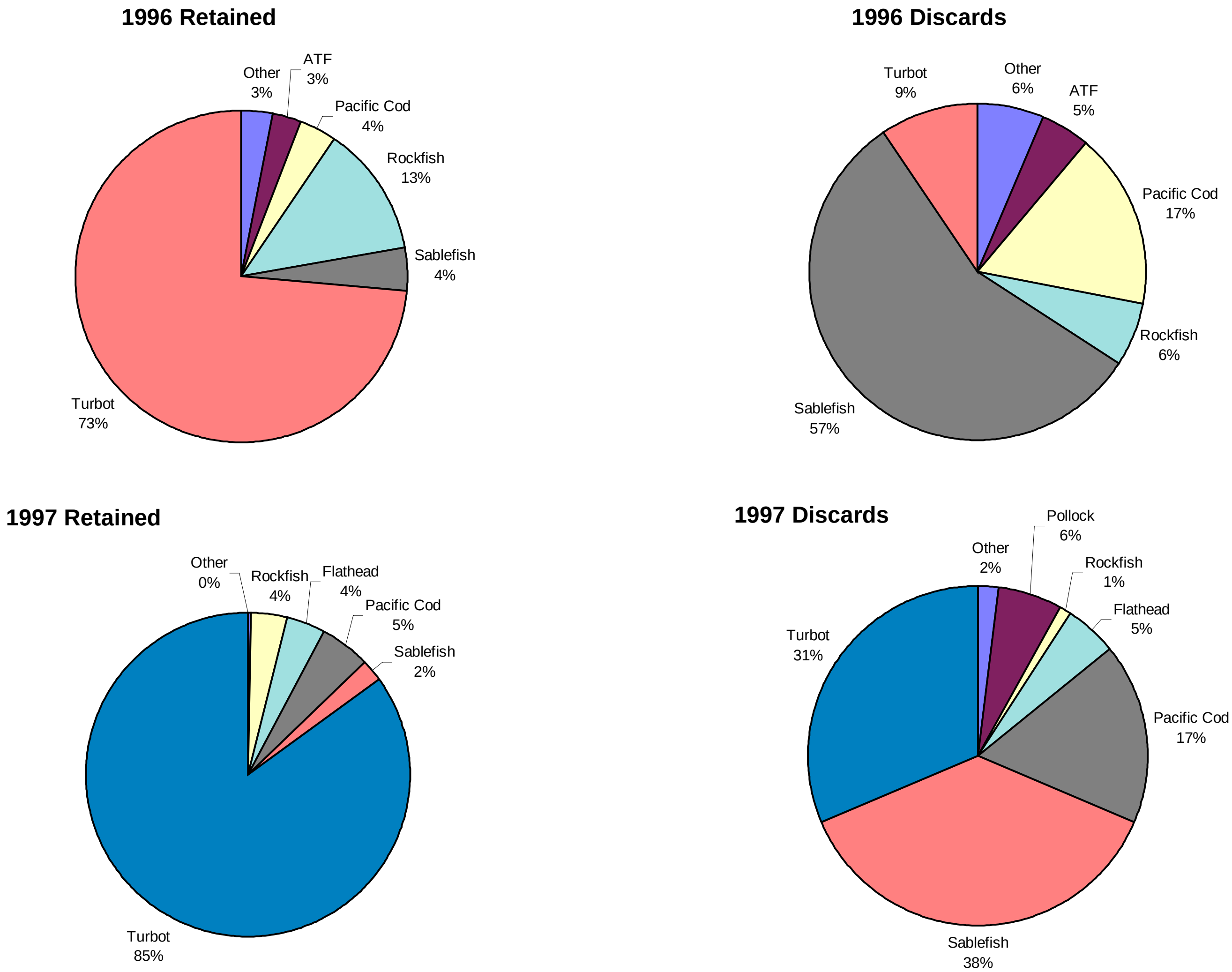



Figure 4.3. 1996 and 1997 retained and discarded Greenland turbot by directed fishery. (Source: AFSC blend database, NOTE: these totals differ slightly from those presented in the text due to differences between catch estimation done "in-season" and that done by analysis of observer *and* weekly processor reports)

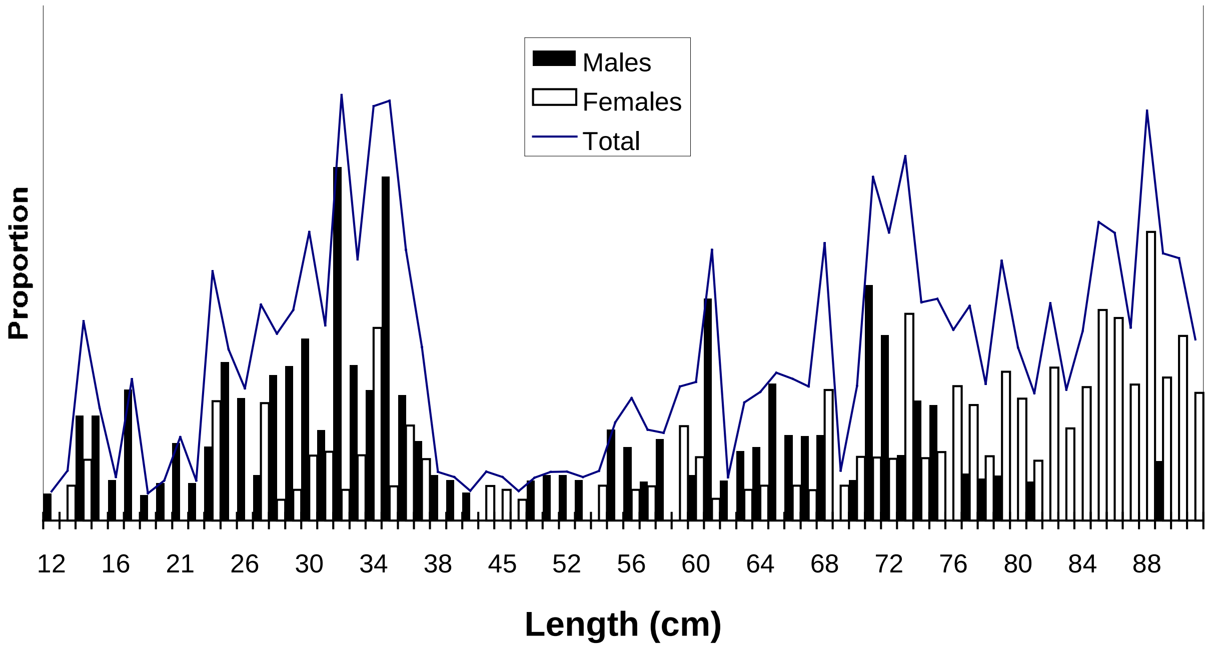



Figure 4.4. Length frequency plot of Greenland turbot from the 1998 shelf trawl survey.

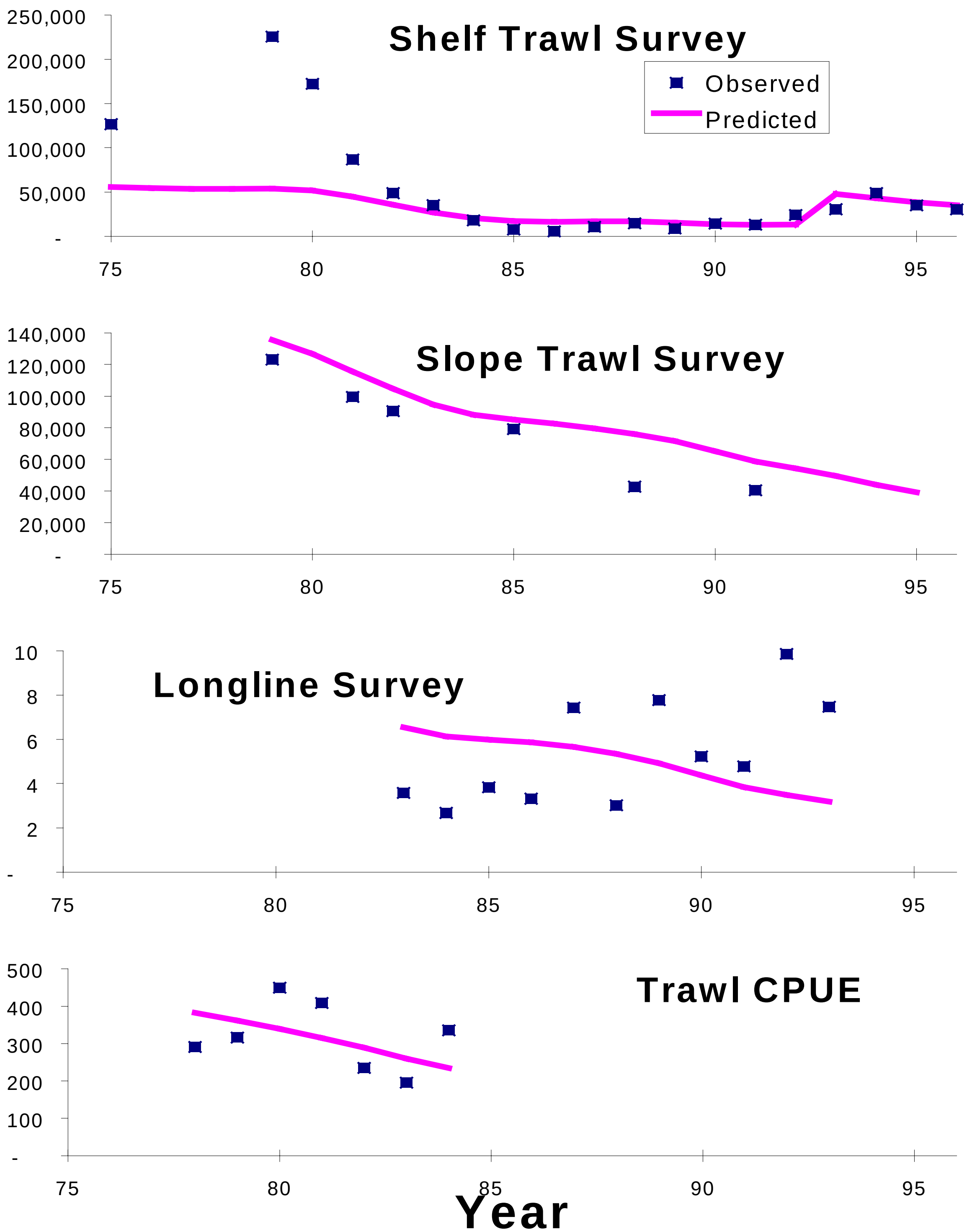



Figure 4.5. Model 2 fits to the different survey and fishery indices for Greenland turbot in the EBS/AI region.

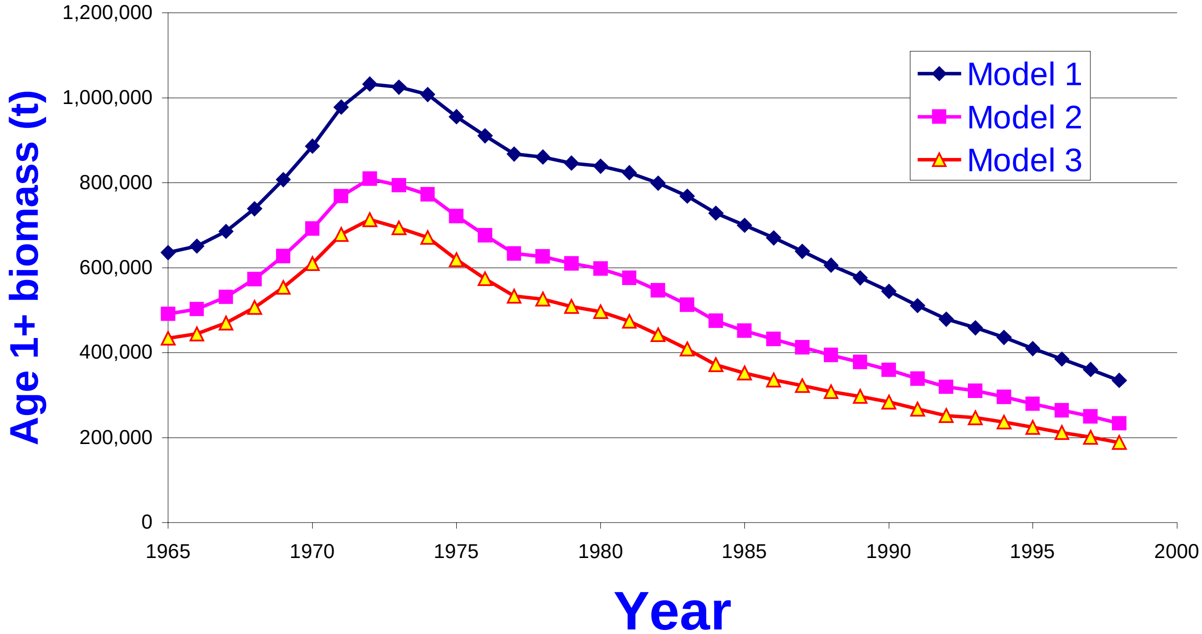



Figure 4.6 Total age 1+ biomass trend for the individual models of Greenland turbot in the EBS/AI region.

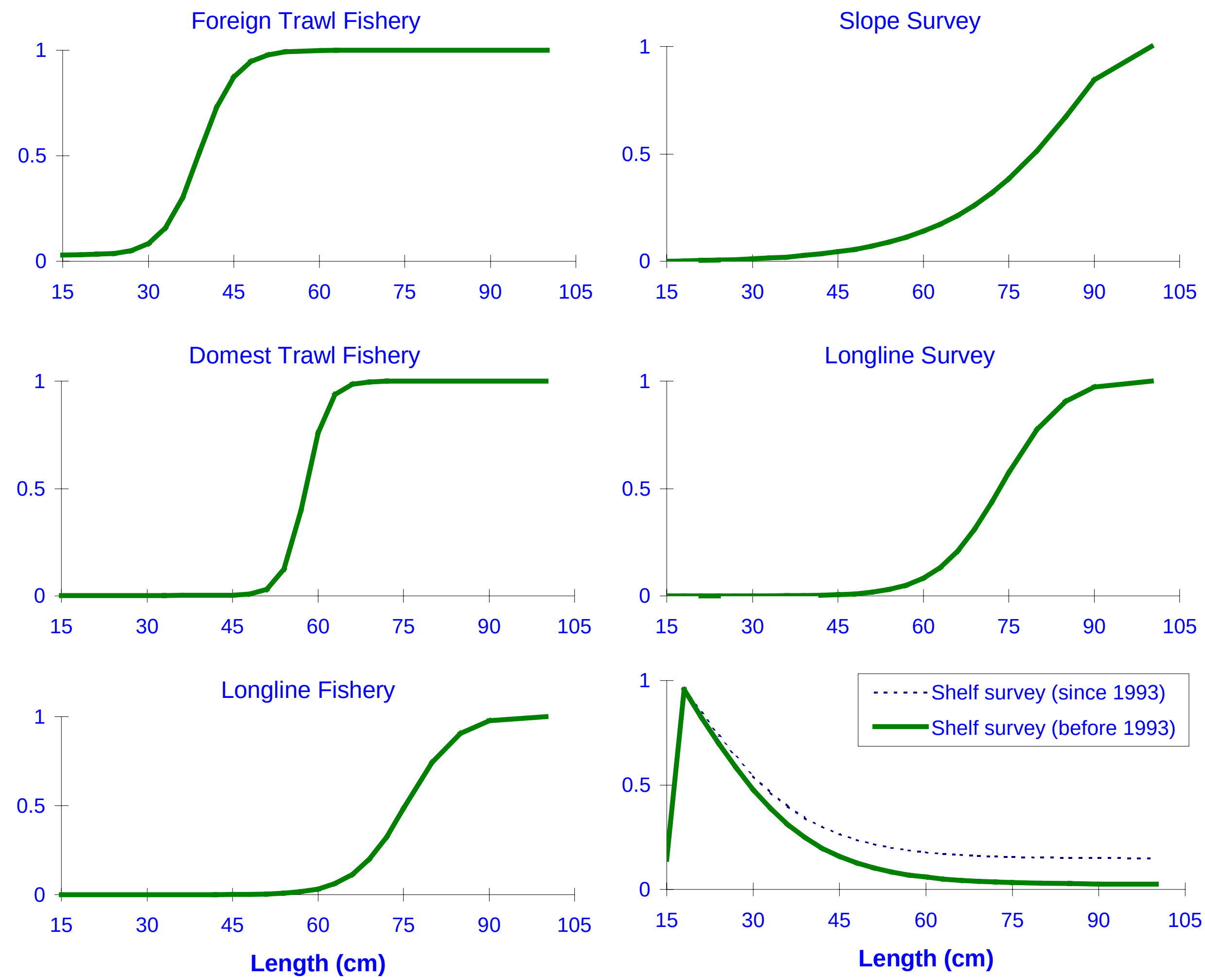



Figure 4.7. Size-specific selectivity patterns for surveys and fisheries of Greenland turbot in the EBS/AI region.

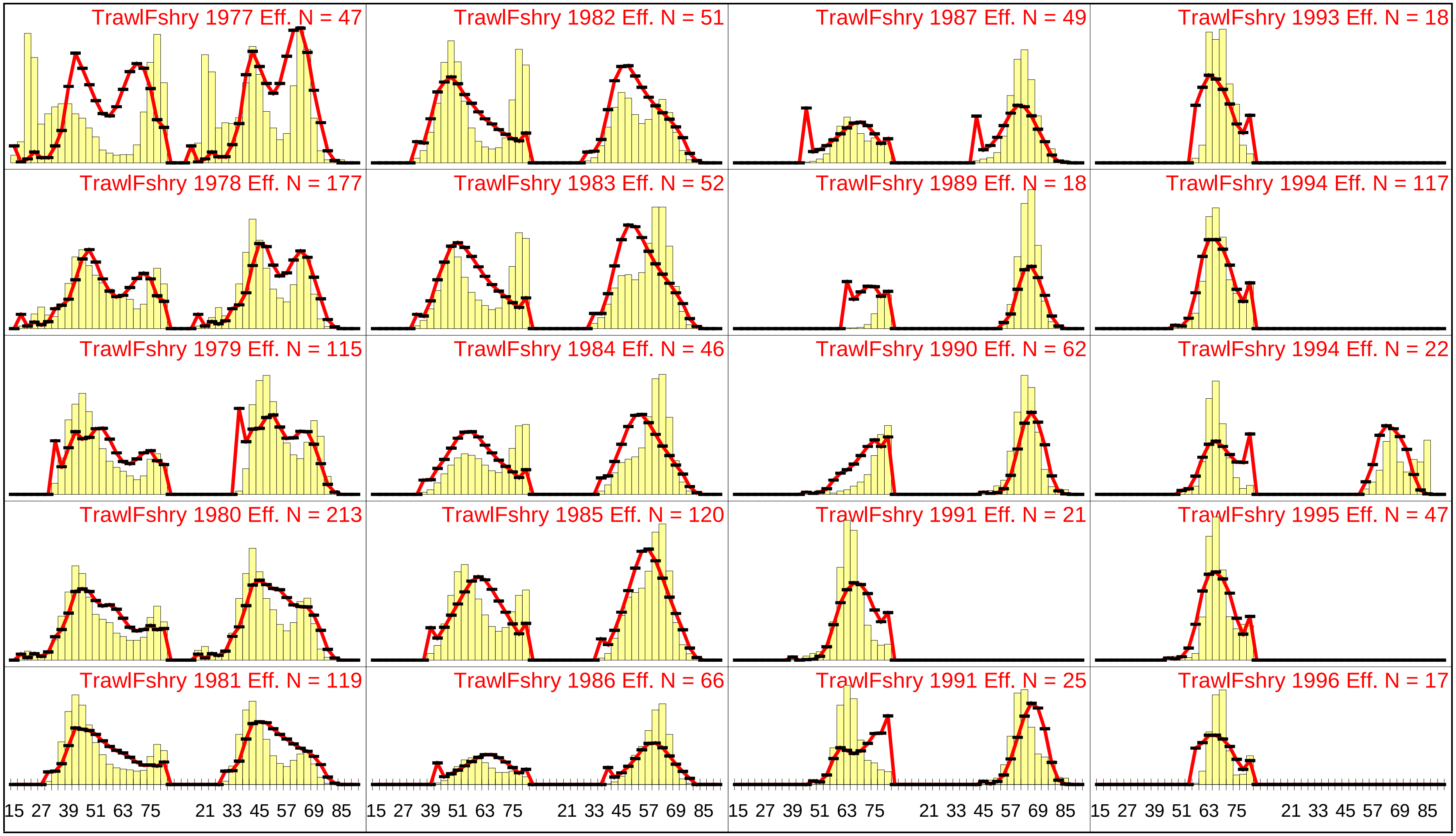



Figure 4.8. Fit to Greenland Turbot **trawl fishery** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

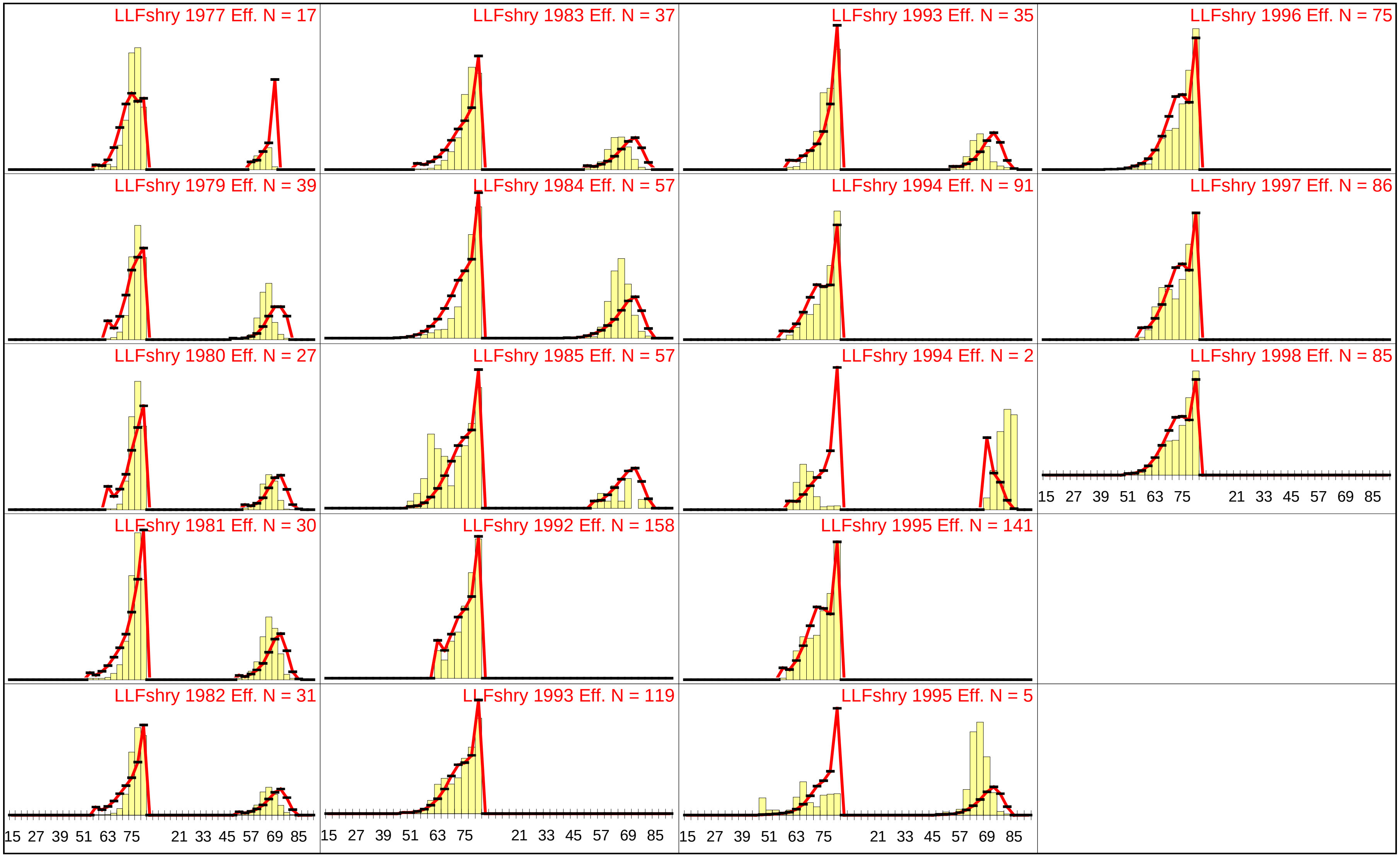



Figure 4.8. (cont'd) Fit to Greenland Turbot **longline fishery** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

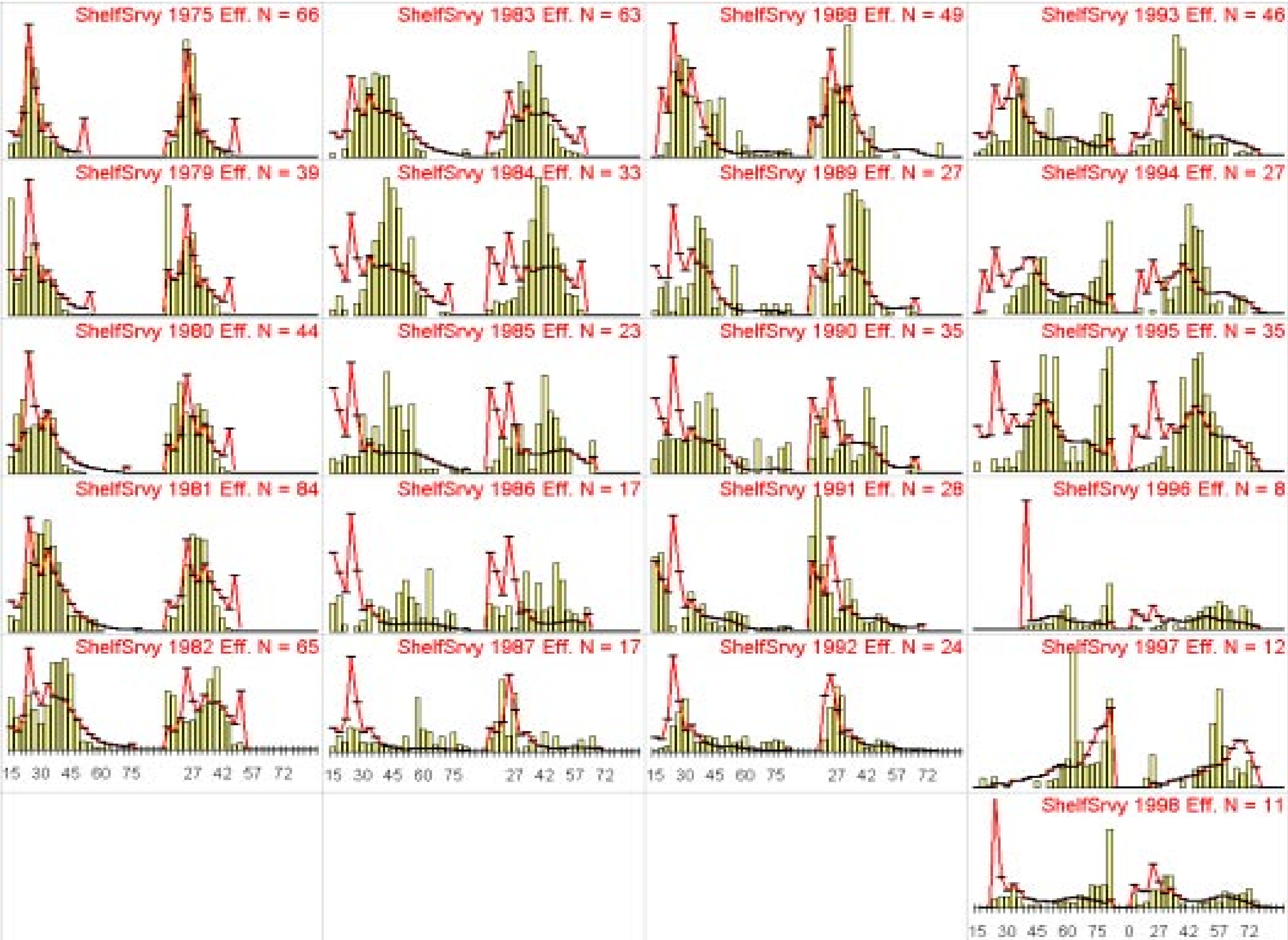



Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS shelf survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

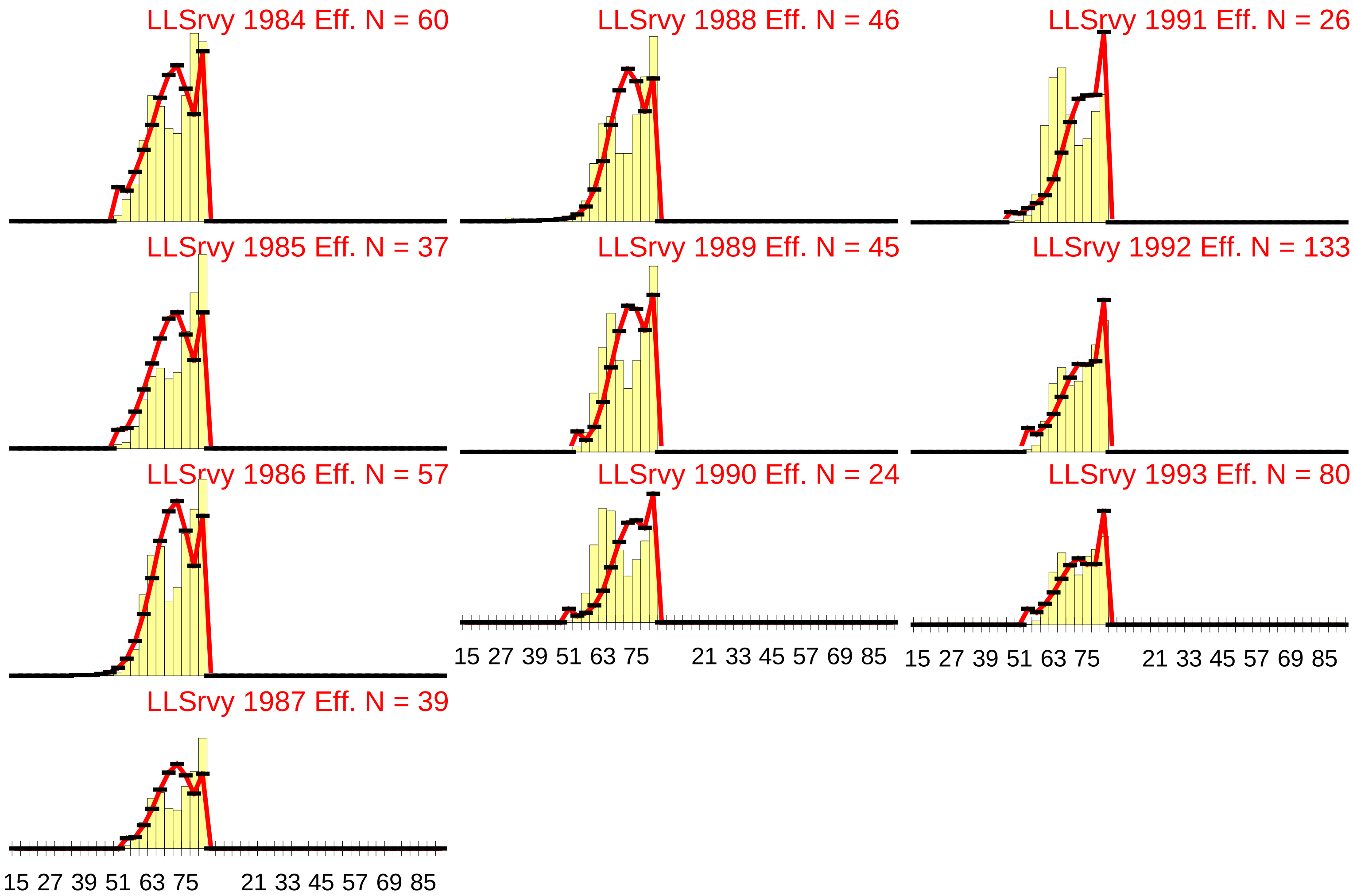



Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS longline survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

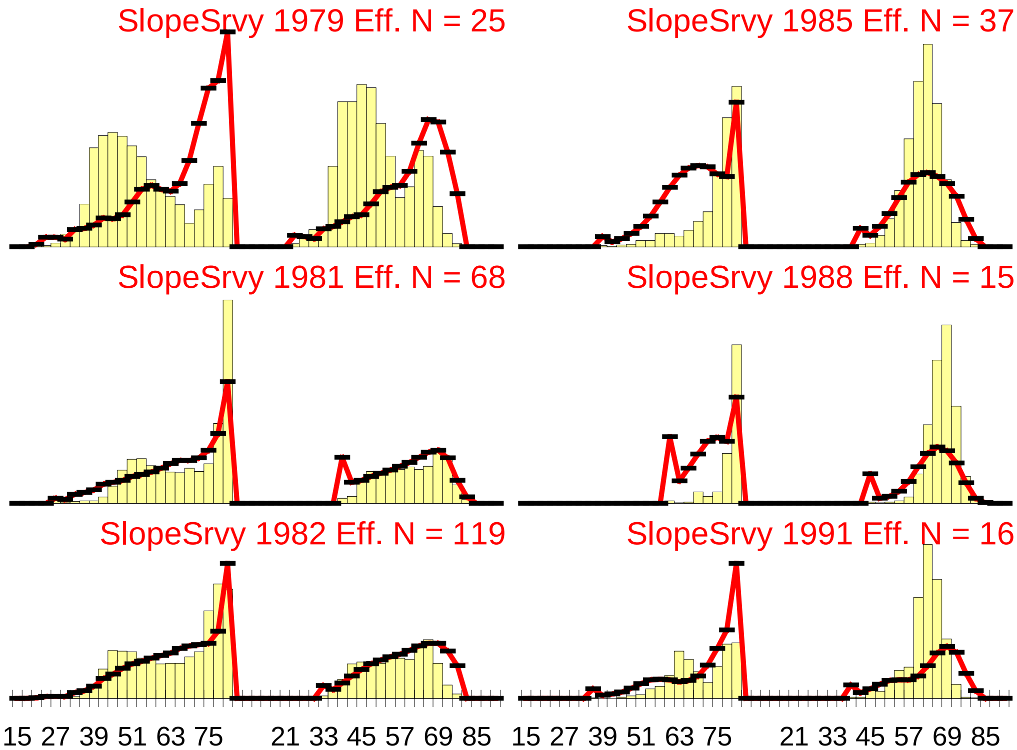



Figure 4.8. (cont'd) Fit to Greenland Turbot **EBS slope trawl survey** length-frequency data. Vertical columns represent data, lines represent predictions from the model. Within each panel, the left-most frequencies are females while males are on the right side. Plots with data on only the left side are for both sexes combined.

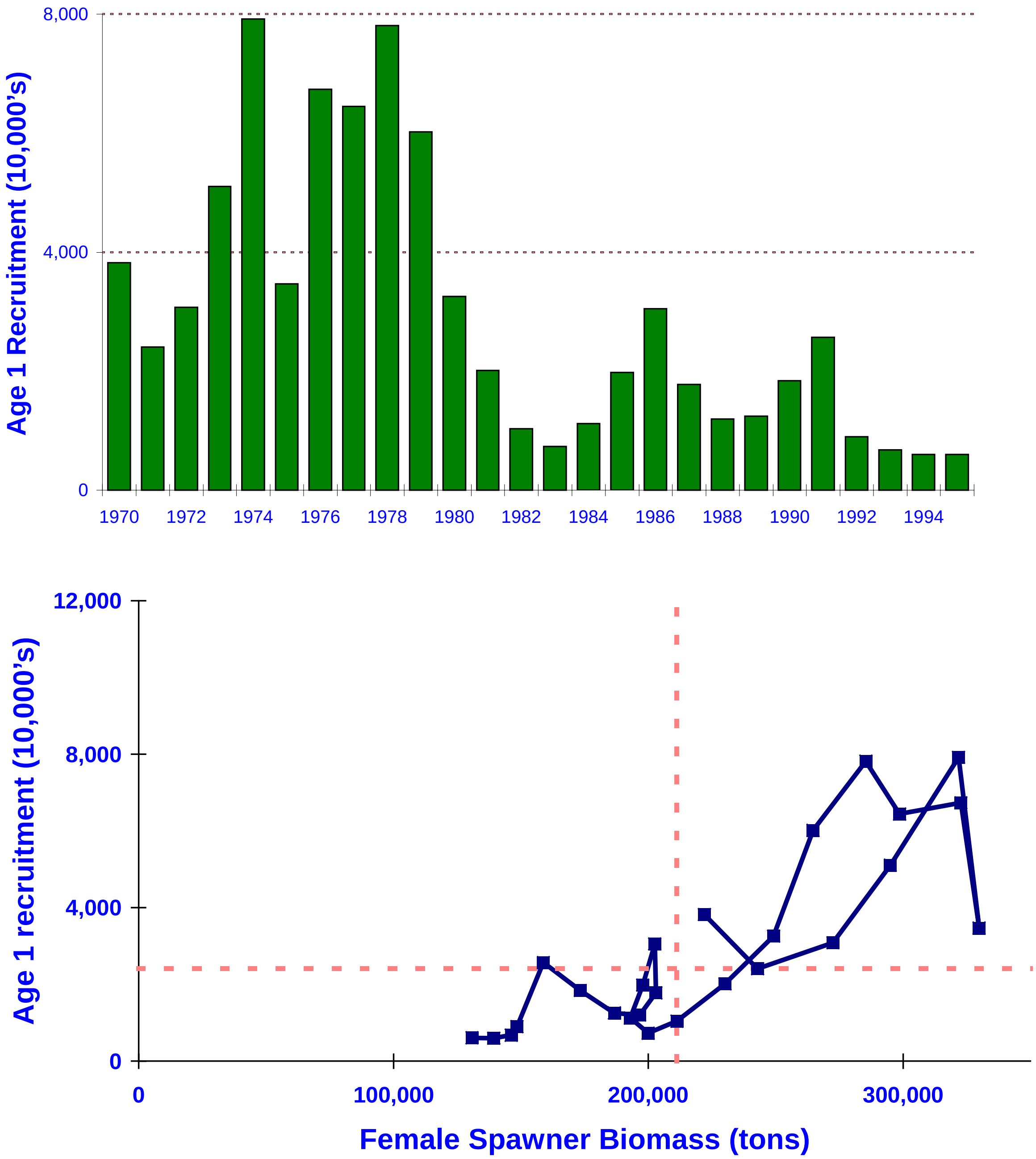



Figure 4.9. Estimated recruitment to age 1 for Model 3 (upper panel) and the observed stock-recruitment pattern (lower panel) of Greenland turbot in the EBS/AI region. Hash lines represent median recruitment and spawner biomass levels.

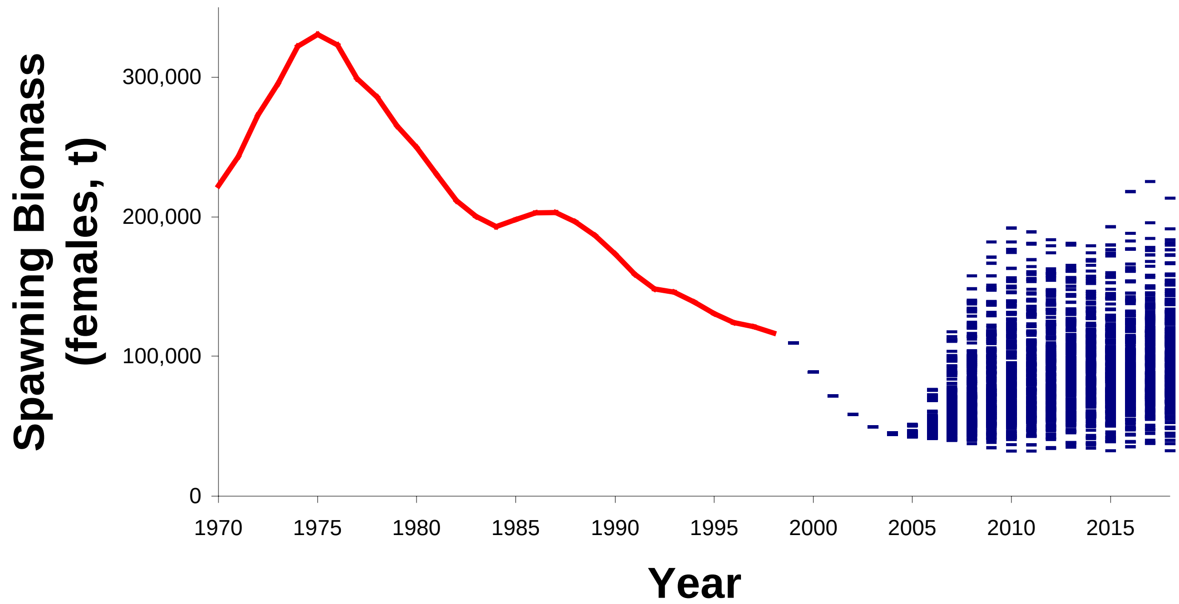



Figure 4.10. An estimated trajectory of female spawner biomass and projected levels for $F_{40\%}$ (unadjusted) harvest rate. These runs are based on Model 3 and assume equal relative fishing mortality rates between longline and trawl fishing gear for the projections.

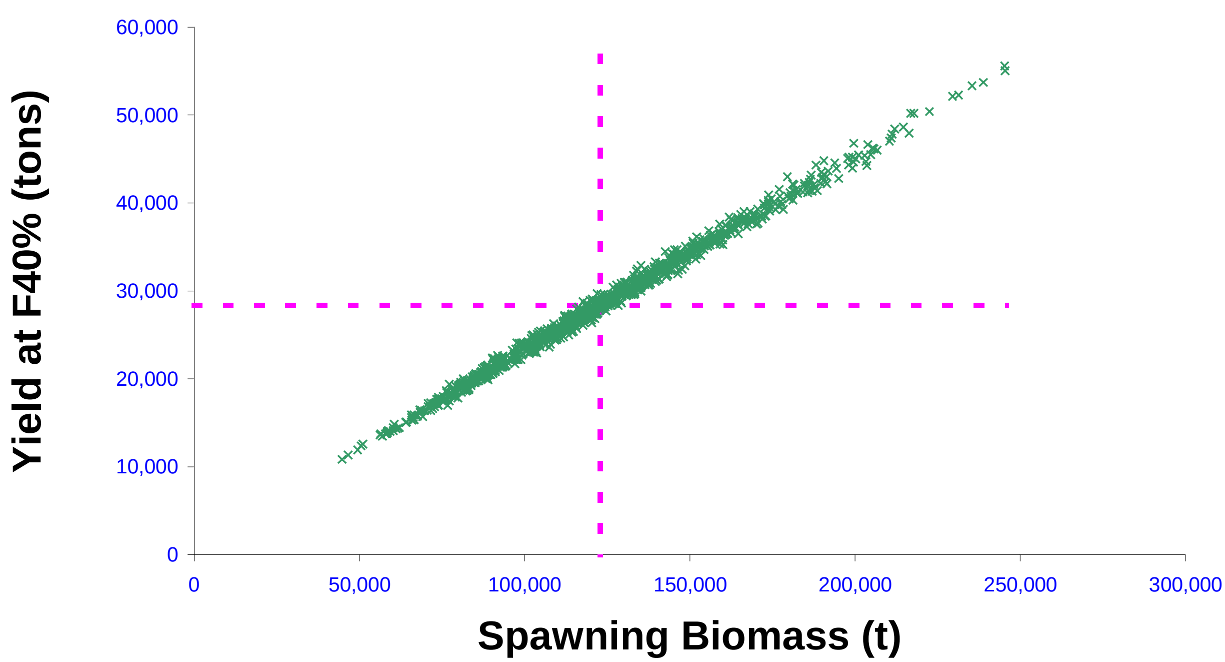



Figure 4.11. Relationship between yield and spawner biomass under the $F_{40\%}$ (no adjustment) harvest rate assuming stochastic resampling ($n$=1,000) of recruitment estimates from 1960-1996. The vertical dashed line represents the mean spawning stock size (which could be interpreted as $B_{40\%}$) and the horizontal line is the mean yield.